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DESCRIPTION

SIGNAL PROCESSING DEVICE AND SIGNAL PROCESSING METHOD, AND

PROGRAM AND RECORDING MEDIUM

5 Technical Field

The present invention relates to a signal processing device and signal processing method, and a program and recording medium, and in particular relates to a signal processing device and signal processing method, and a

10 program and recording medium, enabling images and the like with closer approximation to real world signals.

Background Art

Technology for detecting phenomena in the actual world (real world) with sensors and processing sampling data output from the sensors is widely used. For example, image

15 processing technology wherein the actual world is imaged with an imaging sensor and sampling data which is the image data is processed, is widely employed.

Also, arrangements are known having second dimensions with fewer dimensions than first dimensions obtained by

20 detecting with sensors first signals, which are signals of the real world having first dimensions, obtaining second signals including distortion as to the first signals, and performing signal processing based on the second signals,

25 thereby generating third signals with alleviated distortion

as compared to the second signals (e.g., Japanese Unexamined

Patent Application Publication No. 2001-250119).

However, conventionally, signal processing taking into

consideration the continuity of real world signals had not

5   been performed, so obtaining images and the like which

closer approximate real world signals has been difficult.

Disclosure of Invention

The present invention has been made in light of the

situation as described above, and provides for obtaining of

10   images and the like which closer approximate real world

signals.

A signal processing device according to the present

invention comprises: processing region setting means for

setting the processing region within data, wherein light

15   signals of the real world have been projected on a plurality

of pixels each having time integration effects and a part of

the continuity of the real world light signals has been

lost; movement vector setting means for setting movement

vectors of an object within the image data corresponding to

20   the continuity of the real world light signals of which a

part of the continuity has been lost in the image data;

model generating means for modeling the region between pixel

values of each of the pixels within the processing region

and pixel values of each of the pixels where there is no

25   movement blurring, with the understanding that the pixel

values of each of the pixels within the processing region are values obtained by pixel values of each of the pixels without movement blurring as to the object being integrated while moving corresponding to a movement vector; normal

5 equation generating means for generating normal equations from a first equation wherein the pixel values of the pixels within the processing region have been substituted into a model generated by the model generating means, and a second equation for constraining the relation between the pixels

10 where there is no movement blurring; and actual world estimating means for estimating the pixel values of each of the pixels where there is no movement blurring, by computing the normal equations generated from the normal equation generating means.

15 The normal equation generating means allow a normal equation to be generated from a first equation wherein the pixel values of each of the pixels within the processing region are substituted as to the model generated by the model generating means, and a second equation wherein the

20 difference of the pixel value between each of the pixels not generating movement blurring is zero.

A signal processing method according to the present invention comprises: a processing region setting step for setting the processing region within data, wherein light

25 signals of the real world have been projected on a plurality

of pixels each having time integration effects and a part of

the continuity of the real world light signals has been

lost; a movement vector setting step for setting movement

vectors of an object within the image data corresponding to

5   the continuity of the real world light signals of which a

part of the continuity has been lost in the image data; a

model generating step for modeling the region between pixel

values of each of the pixels within the processing region

and pixel values of each of the pixels where there is no

10 movement blurring, with the understanding that the pixel

values of each of the pixels within the processing region

are values obtained by pixel values of each of the pixels

without movement blurring as to the object being integrated

while moving corresponding to a movement vector; a normal

15. equation generating step for generating normal equations

from a first equation wherein the pixel values of the pixels

within the processing region have been substituted into a

model generated in the model generating step, and a second

equation for constraining the relation between the pixels

20 where there is no movement blurring; and an actual world

estimating step for estimating the pixel values of each of

the pixels where there is no movement blurring, by computing

the normal equations generated from the normal equation

generating step.

25   A program for a recording medium according to the

present invention causes a computer to execute: a processing

region setting step for setting the processing region within

data, wherein light signals of the real world have been

projected on a plurality of pixels each having time

5   integration effects and a part of the continuity of the real

world light signals has been lost; a movement vector setting

step for setting movement vectors of an object within the

image data corresponding to the continuity of the real world

light signals of which a part of the continuity has been

10   lost in the image data; a model generating step for modeling

the region between pixel values of each of the pixels within

the processing region and pixel values of each of the pixels

where there is no movement blurring, with the understanding

that the pixel values of each of the pixels within the

15   processing region are values obtained by pixel values of

each of the pixels without movement blurring as to the

object being integrated while moving corresponding to a

movement vector; a normal equation generating step for

generating normal equations from a first equation wherein

20   the pixel values of the pixels within the processing region

have been substituted into a model generated in the model

generating step, and a second equation for constraining the

relation between the pixels where there is no movement

blurring; and an actual world estimating step for estimating

25   the pixel values of each of the pixels where there is no

movement blurring, by computing the normal equations
generated from the normal equation generating step.

A program according to the present invention causes a
computer to execute: a processing region setting step for
5   setting the processing region within data, wherein light
signals of the real world have been projected on a plurality
of pixels each having time integration effects and a part of
the continuity of the real world light signals has been
lost; a movement vector setting step for setting movement
10   vectors of an object within the image data corresponding to
the continuity of the real world light signals of which a
part of the continuity has been lost in the image data; a
model generating step for modeling the region between pixel
values of each of the pixels within the processing region
15   and pixel values of each of the pixels where there is no
movement blurring, with the understanding that the pixel
values of each of the pixels within the processing region
are values obtained by pixel values of each of the pixels
without movement blurring as to the object being integrated
20   while moving corresponding to a movement vector; a normal
equation generating step for generating normal equations
from a first equation wherein the pixel values of the pixels
within the processing region have been substituted into a
model generated in the model generating step, and a second
25   equation for constraining the relation between the pixels

where there is no movement blurring; and an actual world

estimating step for estimating the pixel values of each of

the pixels where there is no movement blurring, by computing

the normal equations generated from the normal equation

5   generating step.

With the present invention, a light signal of the real

world is projected on multiple pixels, each of which has a

time integration effect, and assuming a processing region is

set within the image data wherein a portion of the

10   continuity of the light signal of the real world has been

lost, and a movement vector of the object within the image

data corresponding to the continuity of the light signal of

the real world wherein a portion of the continuity of the

image data is lost, is set, and the pixel values of each of

15   the pixels within the processing region are said to be a

value integrated while the pixel values of each of the

pixels not generating movement blurring corresponding to the

object is shifted corresponding to the movement vector, and

the relation between the pixel values of each of the pixels

20   of the processing region and the pixel values of each of the

pixels not generating movement blurring is modeled, and a

normal equation is generated as to the model, from the first

equation wherein the pixel values of each of the pixels

within the processing region are substituted and the second

25   equation which constrains the relation between each of the

pixels not generating movement blurring, and by computing the generated normal equation, pixel values for each of the pixels not generating movement blurring can be estimated.

Brief Description of the Drawings

5   Fig. 1 is a diagram illustrating the principle of the present invention.

Fig. 2 is a block diagram illustrating an example of the hardware configuration of a signal processing device 4.

Fig. 3 is a block diagram illustrating a configuration

10   example of an embodiment of the signal processing device 4 shown in Fig. 1.

Fig. 4 is a diagram describing in detail the principle of the signal processing performed by the signal processing device 4.

15   Fig. 5 is a diagram for describing an example of array of pixels on an image sensor.

Fig. 6 is a diagram for describing the operations of a detecting device which is a CCD.

Fig. 7 is a diagram for describing the relation between

20   light cast into detecting elements corresponding to pixel D through pixel F, and pixel values.

Fig. 8 is a diagram describing the relation between elapsing of time, light cast into a detecting element corresponding to one pixel, and pixel values.

25   Fig. 9 is a diagram illustrating an example of an image

of a linear object in the actual world 1.

Fig. 10 is a diagram illustrating an example of pixel values of image data obtained by actual imaging.

Fig. 11 is a diagram illustrating an example of an image of the actual world 1, of an object which is of a color different from that of the background, having a monotone and linear edge.

Fig. 12 is a diagram illustrating an example of pixel values of image data obtained by actual imaging.

Fig. 13 is a schematic diagram of image data.

Fig. 14 is a diagram for describing estimation of a model 161 with M pieces of data 162.

Fig. 15 is a diagram for describing the relation between signals of the actual world 1 and data 3.

Fig. 16 is a diagram illustrating an example of data 3 of interest at the time of creating an Expression.

Fig. 17 is a diagram for describing signals for two objects in the actual world 1, and values belonging to a mixed region at the time of creating an expression.

Fig. 18 is a diagram for describing continuity represented by Expression (18), Expression (19), and Expression (22).

Fig. 19 is a diagram illustrating an example of M pieces of data 162 extracted from data 3.

Fig. 20 is a diagram for describing integration of

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signals of the actual world 1 in the time direction and two-dimensional spatial direction, in the data 3.

Fig. 21 is a diagram for describing an integration region at the time of generating high-resolution data with
5   higher resolution in the spatial direction.

Fig. 22 is a diagram for describing an integration region at the time of generating high-resolution data with higher resolution in the time direction.

Fig. 23 is a diagram for describing an integration
10   region at the time of generating high-resolution data with higher resolution in the time-spatial directions.

Fig. 24 is a diagram illustrating the original image of the input image.

Fig. 25 is a diagram illustrating an example of an
15   input image.

Fig. 26 is a diagram illustrating an image obtained by applying conventional class classification adaptation processing.

Fig. 27 is a diagram illustrating results of detecting
20   a fine line region.

Fig. 28 is a diagram illustrating an example of an output image output from the signal processing device 4.

Fig. 29 is a flowchart for describing signal processing with the signal processing device 4.

25   Fig. 30 is a block diagram illustrating the

configuration of a data continuity detecting unit 101.

Fig. 31 is a diagram illustrating an image in the actual world 1 with a fine line in front of the background.

Fig. 32 is a diagram for describing approximation of a
5   background with a plane.

Fig. 33 is a diagram illustrating the cross-sectional shape of image data regarding which the image of a fine line has been projected.

Fig. 34 is a diagram illustrating the cross-sectional
10   shape of image data regarding which the image of a fine line has been projected.

Fig. 35 is a diagram illustrating the cross-sectional shape of image data regarding which the image of a fine line has been projected.

15   Fig. 36 is a diagram for describing the processing for detecting a peak and detecting of monotonous increase/decrease regions.

Fig. 37 is a diagram for describing the processing for detecting a fine line region wherein the pixel value of the
20   peak exceeds a threshold, while the pixel value of the adjacent pixel is equal to or below the threshold value.

Fig. 38 is a diagram representing the pixel value of pixels arrayed in the direction indicated by dotted line AA' in Fig. 37.

25   Fig. 39 is a diagram for describing processing for

detecting continuity in a monotonous increase/decrease region.

Fig. 40 is a diagram illustrating an example of other processing for detecting regions where an image of a fine line has been projected.

Fig. 41 is a flowchart for describing continuity detection processing.

Fig. 42 is a diagram for describing processing for detecting continuity of data in the time direction.

Fig. 43 is a block diagram illustrating the configuration of a non-continuity component extracting unit 201.

Fig. 44 is a diagram for describing the number of time of rejections.

Fig. 45 is a flowchart describing the processing for extracting the non-continuity component.

Fig. 46 is a flowchart describing the processing for extracting the continuity component.

Fig. 47 is a flowchart describing other processing for extracting the continuity component.

Fig. 48 is a flowchart describing still other processing for extracting the continuity component.

Fig. 49 is a block diagram illustrating another configuration of a continuity component extracting unit 101.

Fig. 50 is a diagram for describing the activity in an

input image having data continuity.

Fig. 51 is a diagram for describing a block for detecting activity.

Fig. 52 is a diagram for describing the angle of data

5   continuity as to activity.

Fig. 53 is a block diagram illustrating a detailed configuration of the data continuity detecting unit 101.

Fig. 54 is a diagram describing a set of pixels.

Fig. 55 is a diagram describing the relation between

10   the position of a pixel set and the angle of data continuity.

Fig. 56 is a flowchart for describing processing for detecting data continuity.

Fig. 57 is a diagram illustrating a set of pixels extracted when detecting the angle of data continuity in the

15   time direction and space direction.

Fig. 58 is a diagram for describing the principle of function approximation, which is an example of an embodiment of the actual world estimating unit shown in Fig. 3.

Fig. 59 is a diagram for describing integration effects

20   in the event that the sensor is a CCD.

Fig. 60 is a diagram for describing a specific example of the integration effects of the sensor shown in Fig. 59.

Fig. 61 is a diagram for describing another specific example of the integration effects of the sensor shown in

25   Fig. 59.

Fig. 62 is a diagram representing a fine-line-inclusive actual world region shown in Fig. 60.

Fig. 63 is a diagram for describing the principle of an example of an embodiment of the actual world estimating unit 5 shown in Fig. 3, in comparison with the example shown in Fig. 58.

Fig. 64 is a diagram representing the fine-line-inclusive data region shown in Fig. 60.

Fig. 65 is a diagram wherein each of the pixel values 10 contained in the fine-line-inclusive data region shown in Fig. 64 are plotted on a graph.

Fig. 66 is a diagram wherein an approximation function, approximating the pixel values contained in the fine-line-inclusive data region shown in Fig. 65, is plotted on a 15 graph.

Fig. 67 is a diagram for describing the continuity in the spatial direction which the fine-line-inclusive actual world region shown in Fig. 60 has.

Fig. 68 is a diagram wherein each of the pixel values 20 contained in the fine-line-inclusive data region shown in Fig. 64 are plotted on a graph.

Fig. 69 is a diagram for describing a state wherein each of the input pixel values indicated in Fig. 68 are shifted by a predetermined shift amount.

25 Fig. 70 is a diagram wherein an approximation function,

approximating the pixel values contained in the fine-line-inclusive data region shown in Fig. 65, is plotted on a graph, taking into consideration the spatial-direction continuity.

5   Fig. 71 is a diagram for describing space-mixed region.

Fig. 72 is a diagram for describing an approximation function approximating actual-world signals in a space-mixed region.

Fig. 73 is a diagram wherein an approximation function, approximating the actual world signals corresponding to the fine-line-inclusive data region shown in Fig. 65, is plotted on a graph, taking into consideration both the sensor integration properties and the spatial-direction continuity.

Fig. 74 is a block diagram for describing a configuration example of the actual world estimating unit using, of function approximation techniques having the principle shown in Fig. 58, primary polynomial approximation.

Fig. 75 is a flowchart for describing actual world estimation processing which the actual world estimating unit of the configuration shown in Fig. 74 executes.

Fig. 76 is a diagram for describing a tap range.

Fig. 77 is a diagram for describing actual world signals having continuity in the spatial direction.

Fig. 78 is a diagram for describing integration effects in the event that the sensor is a CCD.

Fig. 79 is a diagram for describing distance in the cross-sectional direction.

Fig. 80 is a block diagram for describing a configuration example of the actual world estimating unit
5   using, of function approximation techniques having the principle shown in Fig. 58, quadratic polynomial approximation.

Fig. 81 is a flowchart for describing actual world estimation processing which the actual world estimating unit
10   of the configuration shown in Fig. 80 executes.

Fig. 82 is a diagram for describing a tap range.

Fig. 83 is a diagram for describing direction of continuity in the time-spatial direction.

Fig. 84 is a diagram for describing integration effects
15   in the event that the sensor is a CCD.

Fig. 85 is a diagram for describing actual world signals having continuity in the spatial direction.

Fig. 86 is a diagram for describing actual world signals having continuity in the space-time directions.

20   Fig. 87 is a block diagram for describing a configuration example of the actual world estimating unit using, of function approximation techniques having the principle shown in Fig. 58, cubic polynomial approximation.

Fig. 88 is a flowchart for describing actual world
25   estimation processing which the actual world estimating unit

of the configuration shown in Fig. 87 executes.

Fig. 89 is a diagram for describing the principle of re-integration, which is an example of an embodiment of the image generating unit shown in Fig. 3.

5   Fig. 90 is a diagram for describing an example of an input pixel and an approximation function for approximation of an actual world signal corresponding to the input pixel.

Fig. 91 is a diagram for describing an example of creating four high-resolution pixels in the one input pixel shown in Fig. 90, from the approximation function shown in

10   Fig. 90.

Fig. 92 is a block diagram for describing a configuration example of an image generating unit using, of re-integration techniques having the principle shown in Fig.

15   89, one-dimensional re-integration technique.

Fig. 93 is a flowchart for describing the image generating processing which the image generating unit of the configuration shown in Fig. 92 executes.

Fig. 94 is a diagram illustrating an example of the

20   original image of the input image.

Fig. 95 is a diagram illustrating an example of image data corresponding to the image shown in Fig. 94.

Fig. 96 is a diagram representing an example of an input image.

25   Fig. 97 is a diagram representing an example of image

data corresponding to the image shown in Fig. 96.

Fig. 98 is a diagram illustrating an example of an image obtained by subjecting an input image to conventional class classification adaptation processing.

5　　　Fig. 99 is a diagram representing an example of image data corresponding to the image shown in Fig. 98.

Fig. 100 is a diagram illustrating an example of an image obtained by subjecting an input image to the one-dimensional re-integration technique.

10　　Fig. 101 is a diagram illustrating an example of image data corresponding to the image shown in Fig. 100.

Fig. 102 is a diagram for describing actual-world signals having continuity in the spatial direction.

Fig. 103 is a block diagram for describing a

15　configuration example of an image generating unit which uses, of the re-integration techniques having the principle shown in Fig. 89, a two-dimensional re-integration technique.

Fig. 104 is a diagram for describing distance in the cross-sectional direction.

20　　Fig. 105 is a flowchart for describing the image generating processing which the image generating unit of the configuration shown in Fig. 103 executes.

Fig. 106 is a diagram for describing an example of an input pixel.

25　　Fig. 107 is a diagram for describing an example of

creating four high-resolution pixels in the one input pixel shown in Fig. 106, with the two-dimensional re-integration technique.

Fig. 108 is a diagram for describing the direction of continuity in the space-time directions.

Fig. 109 is a block diagram for describing a configuration example of the image generating unit which uses, of the re-integration techniques having the principle shown in Fig. 89, a three-dimensional re-integration technique.

Fig. 110 is a flowchart for describing the image generating processing which the image generating unit of the configuration shown in Fig. 109 executes.

Fig. 111 is a block diagram illustrating a configuration example of another embodiment of the signal processing device 4 shown in Fig. 1.

Fig. 112 is a flowchart for describing the processing of the signal processing device 4 shown in Fig. 111.

Fig. 113 is a block diagram illustrating a configuration example of an applied embodiment of the signal processing device 4 shown in Fig. 111.

Fig. 114 is a flowchart for describing the processing of the signal processing device 4 shown in Fig. 113.

Fig. 115 is a diagram describing a light signal of an actual world 1.

Fig. 116 is a diagram describing the integration effect in the event that the sensor 2 is a CCD.

Fig. 117 is a diagram showing an approximation function f(x,y) of the actual world 1.

5   Fig. 118 is a diagram describing an input image to be input in the signal processing device 4 of Fig. 113, and a processing region.

Fig. 119 is a diagram describing an example of a processing region set in the signal processing device 4 of

10   the Fig. 113.

Fig. 120 is a diagram illustrating an approximation function f(x) of the X cross-section, wherein the value of y within the approximation function f(x,y) in Fig. 120 is a predetermined value y_c (y = y_c).

15   Fig. 121 is a diagram showing the approximation function f(x) in Fig. 120 after 1/v time has passed.

Fig. 122 is a diagram showing the approximation function f(x) in Fig. 121 after 1/v time has passed.

Fig. 123 is a diagram describing the movement of the

20   object to be imaged in the input image moves v pixels for every shutter time.

Fig. 124 is a diagram showing the approximation function f(x) of y = y_c at a predetermined precise timing, illustrated in Fig. 120, with a X - t plane.

25   Fig. 125 is a diagram showing pixel values P_0 through P_9

generating movement blurring, with a X - t plane, so as to correspond with the pixel values Q_0 through Q_9 in Fig. 124.

Fig. 126 is a diagram showing the pixel values P_0 through P_9 of an input image with the pixel values Q_0 through Q_9 in Fig. 124.

Fig. 127 is a diagram describing a method for solving the blank regions in Fig. 126, hypothesizing the edge portions of the processing region as "being flat".

Fig. 128 is a diagram describing the line of interest of the processing region in Fig. 119.

Fig. 129 is a block diagram illustrating a configuration example of the actual world estimating unit 15013 in Fig. 113.

Fig. 130 is a flowchart describing the actual world estimating processing of step S15008 in Fig. 114.

Fig. 131 is a flowchart describing the actual world estimating processing of step S15008 in Fig. 114.

Fig. 132 is a diagram illustrating the input image to be input into the signal processing device 4 in Fig. 113.

Fig. 133 is a diagram illustrating a processed and output image wherein the signal processing device 4 in Fig. 113 has processed the input image in Fig. 132 with the first method, which adds an equation which is postulated as having the edge portions of the processing regions as "being flat".

Fig. 134 is a diagram illustrating a processed and

output image wherein the signal processing device 4 in Fig. 113 has processed the input image in Fig. 132 with the second method, which adds a conditional expression constraining the relation between the adjacent pixel values.

5   Fig. 135 is a block diagram of a configuration example of another embodiment of an application example of the signal processing device 4 in Fig. 111.

Fig. 136 is a flowchart describing the processing of the signal processing device 4 in Fig. 135.

10   Fig. 137 is a block diagram illustrating a configuration example of the actual world estimating unit 15083 in Fig. 135.

Fig. 138 is a flowchart describing the actual world estimating processing in step S15088 in Fig. 136.

15   Fig. 139 is a flowchart describing the actual world estimating processing in step S15088 in Fig. 136.

Fig. 140 is a block diagram of a configuration example of another embodiment of an application example of the signal processing device 4 in Fig. 111.

20   Fig. 141 is a flowchart describing the processing of the signal processing device 4 in Fig. 140.

Fig. 142 is a block diagram illustrating a configuration example of the actual world estimating unit 15113 in Fig. 140.

25   Fig. 143 is a flowchart describing the actual world

estimating processing in step S15168 in Fig. 141.

Fig. 144 is a diagram illustrating the input image which is input into the signal processing device 4 in Fig. 140.

5   Fig. 145 is a diagram illustrating an example of an output image wherein the signal processing device 4 in Fig. 135 processes the input image in Fig. 144 using the weighting W_{bj} corresponding to the constraint condition expression as the same weighting for all of the constraint

10   condition expressions.

Fig. 146 is a diagram illustrating an example of an output image wherein the signal processing device 4 in Fig. 140 processes the input image in Fig. 144 using the weighting W_{bj} corresponding to the constraint condition

15   expression as a 0 or a 1, according to the activity of the input image.

Fig. 147 is a block diagram of a configuration example of another embodiment of an application example of the signal processing device 4 in Fig. 111.

20   Fig. 148 is a flowchart describing the processing of the signal processing device 4 in Fig. 147.

Fig. 149 is a block diagram illustrating a configuration example of the actual world estimating unit 15153 in Fig. 147.

25   Fig. 150 is a flowchart for describing the actual world

estimating processing in step S15218 in Fig. 148.

Fig. 151 is a flowchart for describing the actual world estimating processing in step S15218 in Fig. 148.

Fig. 152 is a block diagram illustrating a
5 configuration example of a continuity setting unit 15012 shown in Fig. 113.

Fig. 153 is a diagram for describing amount of movement.

Fig. 154 is a diagram illustrating pixel values of an image output from a camera, taken by the camera while a
10 foreground object passes in front of a background object.

Fig. 155 is a diagram illustrating difference values of the pixel values of pixels in the image shown in Fig. 154.

Fig. 156 is a flowchart for describing processing for detecting amount of movement.

15 Fig. 157 is a flowchart for describing processing for detecting correlation.

Best Mode for Carrying Out the Invention

Fig. 1 illustrates the principle of the present invention. As shown in the drawing, events (phenomena) in
20 an actual world 1 having dimensions of space, time, and mass, are acquired by a sensor 2, and formed into data. Events in the actual world 1 refer to light (images), sound, pressure, temperature, mass, humidity, brightness/darkness, or smells, and so forth. The events in the actual world 1 are
25 distributed in the space-time directions. For example, an

image of the actual world 1 is a distribution of the intensity of light of the actual world 1 in the space-time directions.

Taking note of the sensor 2, of the events in the actual world 1 having the dimensions of space, time, and mass, the events in the actual world 1 which the sensor 2 can acquire, are converted into data 3 by the sensor 2. It can be said that information indicating events in the actual world 1 are acquired by the sensor 2.

That is to say, the sensor 2 converts information indicating events in the actual world 1, into data 3. It can be said that signals which are information indicating the events (phenomena) in the actual world 1 having dimensions of space, time, and mass, are acquired by the sensor 2 and formed into data.

Hereafter, the distribution of events such as images, sound, pressure, temperature, mass, humidity, brightness/darkness, or smells, and so forth, in the actual world 1, will be referred to as signals of the actual world 1, which are information indicating events. Also, signals which are information indicating events of the actual world 1 will also be referred to simply as signals of the actual world 1. In the present Specification, signals are to be understood to include phenomena and events, and also include those wherein there is no intent on the transmitting side.

The data 3 (detected signals) output from the sensor 2 is information obtained by projecting the information indicating the events of the actual world 1 on a space-time having a lower dimension than the actual world 1. For

5 example, the data 3 which is image data of a moving image, is information obtained by projecting an image of the three-dimensional space direction and time direction of the actual world 1 on the time-space having the two-dimensional space direction and time direction. Also, in the event that the

10 data 3 is digital data for example, the data 3 is rounded off according to the sampling increments. In the event that the data 3 is analog data, information of the data 3 is either compressed according to the dynamic range, or a part of the information has been deleted by a limiter or the like.

15   Thus, by projecting the signals shown are information indicating events in the actual world 1 having a predetermined number of dimensions onto data 3 (detection signals), a part of the information indicating events in the actual world 1 is lost. That is to say, a part of the

20 information indicating events in the actual world 1 is lost from the data 3 which the sensor 2 outputs.

However, even though a part of the information indicating events in the actual world 1 is lost due to projection, the data 3 includes useful information for

25 estimating the signals which are information indicating

events (phenomena) in the actual world 1.

With the present invention, information having
continuity contained in the actual world 1 or the data 3 is
used as useful information for estimating the signals which
5   is information of the actual world 1. Continuity is a
concept which is newly defined.

Taking note of the actual world 1, events in the actual
world 1 include characteristics which are constant in
predetermined dimensional directions. For example, an
10   object (corporeal object) in the actual world 1 either has
shape, pattern, or color that is continuous in the space
direction or time direction, or has repeated patterns of
shape, pattern, or color.

Accordingly, the information indicating the events in
15   actual world 1 includes characteristics constant in a
predetermined dimensional direction.

With a more specific example, a linear object such as a
string, cord, or rope, has a characteristic which is
constant in the length-wise direction, i.e., the spatial
20   direction, that the cross-sectional shape is the same at
arbitrary positions in the length-wise direction. The
continuity in the spatial direction that the cross-sectional
shape is the same at arbitrary positions in the length-wise
direction comes from the characteristic that the linear
25   object is long.

Accordingly, an image of the linear object has a characteristic which is constant in the length-wise direction, i.e., the spatial direction, that the cross-sectional shape is the same, at arbitrary positions in the length-wise direction.

Also, a monotone object, which is a corporeal object, having an expanse in the spatial direction, can be said to have a continuity of having the same color in the spatial direction regardless of the part thereof.

In the same way, an image of a monotone object, which is a corporeal object, having an expanse in the spatial direction, have a continuity of having the same color in the spatial direction regardless of the part thereof.

In this way, events in the actual world 1 (real world) have characteristics which are constant in predetermined dimensional directions, so signals of the actual world 1 have characteristics which are constant in predetermined dimensional directions

In the present Specification, such characteristics which are constant in predetermined dimensional directions will be called continuity. Continuity of the signals of the actual world 1 (real world) means the characteristics which are constant in predetermined dimensional directions which the signals indicating the events of the actual world 1 (real world) have.

Countless such continuities exist in the actual world 1 (real world).

Next, taking note of the data 3, the data 3 is obtained by signals which is information indicating events of the
5   actual world 1 having predetermined dimensions being projected by the sensor 2, and includes continuity corresponding to the continuity of signals in the real world. It can be said that the data 3 includes continuity wherein the continuity of actual world signals has been projected.

10   However, as described above, in the data 3 output from the sensor 2, a part of the information of the actual world 1 has been lost, so a part of the continuity contained in the signals of the actual world 1 (real world) may be lost from the data.

15   In other words, the data 3 contains at least a part of the continuity within the continuity of the signals of the actual world 1 (real world) as data continuity. Data continuity means characteristics which are constant in predetermined dimensional directions, which the data 3 has.

20   With the present invention, continuity of the actual world 1 signals, or the data continuity which the data 3 has, is used as significant data for estimating signals which are information indicating events of the actual world 1.

For example, with the signal processing device 4,
25   information indicating an event in the actual world 1 which

has been lost is generated by signals processing of the data 3, using data continuity.

Now, with the signal processing device 4, of the length (space), time, and mass, which are dimensions of signals

5   serving as information indicating events in the actual world 1, continuity in the spatial direction or time direction, are used.

In Fig. 1, the sensor 2 is formed of, for example, a digital still camera, a video camera, or the like, and takes

10   images of the actual world 1, and outputs the image data which is the obtained data 3, to a signal processing device 4. The sensor 2 may also be a thermography device, a pressure sensor using photo-elasticity, or the like.

The signal processing device 4 is configured of, for

15   example, a personal computer or the like, and performs signal processing with regard to the data 3.

The signal processing device 4 is configured as shown in Fig. 2, for example. A CPU (Central Processing Unit) 21 executes various types of processing following programs

20   stored in ROM (Read Only Memory) 22 or the storage unit 28. RAM (Random Access Memory) 23 stores programs to be executed by the CPU 21, data, and so forth, as suitable. The CPU 21, ROM 22, and RAM 23, are mutually connected by a bus 24.

Also connected to the CPU 21 is an input/output

25   interface 25 via the bus 24. An input device 26 made up of

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a keyboard, mouse, microphone, and so forth, and an output
unit 27 made up of a display, speaker, and so forth, are
connected to the input/output interface 25. The CPU 21
executes various types of processing corresponding to
5   commands input from the input unit 26. The CPU 21 then
outputs images and audio and the like obtained as a result
of processing to the output unit 27.

   A storage unit 28 connected to the input/output
interface 25 is configured of a hard disk for example, and
10   stores the programs and various types of data which the CPU
21 executes. A communication unit 29 communicates with
external devices via the Internet and other networks. In
the case of this example, the communication unit 29 acts as
an acquiring unit for capturing data 3 output from the
15   sensor 2.

   Also, an arrangement may be made wherein programs are
obtained via the communication unit 29 and stored in the
storage unit 28.

   A drive 30 connected to the input/output interface 25
20   drives a magnetic disk 51, optical disk 52, magneto-optical
disk 53, or semiconductor memory 54 or the like mounted
thereto, and obtains programs and data recorded therein.
The obtained programs and data are transferred to the
storage unit 28 as necessary and stored.

25   Fig. 3 is a block diagram illustrating a signal

processing device 4.

Note that whether the functions of the signal processing device 4 are realized by hardware or realized by software is irrelevant. That is to say, the block diagrams
5   in the present Specification may be taken to be hardware block diagrams or may be taken to be software function block diagrams.

With the signal processing device 4 of which the configuration is shown in Fig. 3, image data which is an
10   example of the data 3 is input, and the continuity of the data is detected from the input image data (input image). Next, the signals of the actual world 1 acquired by the sensor 2 are estimated from the continuity of the data detected. Then, based on the estimated signals of the
15   actual world 1, an image is generated, and the generated image (output image) is output. That is to say, Fig. 3 is a diagram illustrating the configuration of the signal processing device 4 which is an image processing device.

The input image (image data which is an example of the
20   data 3) input to the signal processing device 4 is supplied to a data continuity detecting unit 101 and actual world estimating unit 102.

The data continuity detecting unit 101 detects the continuity of the data from the input image, and supplies
25   data continuity information indicating the detected

continuity to the actual world estimating unit 102 and an
image generating unit 103. The data continuity information
includes, for example, the position of a region of pixels
having continuity of data, the direction of a region of
5   pixels having continuity of data (the angle or gradient of
the time direction and space direction), or the length of a
region of pixels having continuity of data, or the like in
the input image. Detailed configuration of the data
continuity detecting unit 101 will be described later.
10   The actual world estimating unit 102 estimates the signals
of the actual world 1, based on the input image and the data
continuity information supplied from the data continuity
detecting unit 101. That is to say, the actual world
estimating unit 102 estimates an image which is the signals
15   of the actual world cast into the sensor 2 at the time that
the input image was acquired. The actual world estimating
unit 102 supplies the actual world estimation information
indicating the results of the estimation of the signals of
the actual world 1, to the image generating unit 103. The
20   detailed configuration of the actual world estimating unit
102 will be described later.

The image generating unit 103 generates signals further
approximating the signals of the actual world 1, based on
the actual world estimation information indicating the
25   estimated signals of the actual world 1, supplied from the

actual world estimating unit 102, and outputs the generated signals. Or, the image generating unit 103 generates signals further approximating the signals of the actual world 1, based on the data continuity information supplied

5 from the data continuity detecting unit 101, and the actual world estimation information indicating the estimated signals of the actual world 1, supplied from the actual world estimating unit 102, and outputs the generated signals.

That is to say, the image generating unit 103 generates

10 an image further approximating the image of the actual world 1 based on the actual world estimation information, and outputs the generated image as an output image. Or, the image generating unit 103 generates an image further approximating the image of the actual world 1 based on the

15 data continuity information and actual world estimation information, and outputs the generated image as an output image.

For example, the image generating unit 103 generates an image with higher resolution in the spatial direction or

20 time direction in comparison with the input image, by integrating the estimated image of the actual world 1 within a desired range of the spatial direction or time direction, based on the actual world estimation information, and outputs the generated image as an output image. For example,

25 the image generating unit 103 generates an image by

extrapolation/interpolation, and outputs the generated image as an output image.

Detailed configuration of the image generating unit 103 will be described later.

5   Next, the principle of the present invention will be described with reference to Fig. 4.

For example, signals of the actual world 1, which are an image for example, are imaged on the photoreception face of a CCD (Charge Coupled Device) which is an example of the

10   sensor 2. The CCD, which is an example of the sensor 2, has integration properties, so difference is generated in the data 3 output from the CCD as to the image of the actual world 1. Details of the integration properties of the sensor 2 will be described later.

15   With the signal processing by the signal processing device 4, the relation between the image of the actual world 1 obtained by the CCD, and the data 3 taken by the CCD and output, is explicitly taken into consideration. That is to say, the relation between the data 3 and the signals which

20   is information of the actual world obtained by the sensor 2, is explicitly taken into consideration.

More specifically, as shown in Fig. 4, the signal processing device 4 uses a model 161 to approximate (describe) the actual world 1. The model 161 is represented

25   by, for example, N variables. More accurately, the model

161 approximates (describes) signals of the actual world 1.

In order to predict the model 161, the signal processing device 4 extracts M pieces of data 162 from the data 3. At the time of extracting the M pieces of data 162 from the data 3, the signal processing device 4 uses the continuity of the data contained in the data 3, for example. In other words, the signal processing device 4 extracts data 162 for predicting the model 161, based on the continuity of the data contained in the data 3. Consequently, in this case, the model 161 is constrained by the continuity of the data.

That is to say, the model 161 approximates (information (signals) indicating) events of the actual world 1 having continuity (continuity in a predetermined dimensional direction), which generates the data continuity in the data 3 when acquired with the sensor 2.

Now, in the event that the number M of the data 162 is N or more, which is the number of variables of the model, the model 161 represented by the N variables can be predicted, from the M pieces of the data 162.

In this way, the signal processing device 4 can take into consideration the signals which are information of the actual world 1, by predicting the model 161 approximating (describing) the (signals of the) actual world 1.

Next, the integration effects of the sensor 2 will be

described.

An image sensor such as a CCD or CMOS (Complementary Metal-Oxide Semiconductor) sensor or the like, which is the sensor 2 for taking images, projects signals, which are

5   information of the real world, onto two-dimensional data, at the time of imaging the real world. The pixels of the image sensor each have a predetermined area, as a so-called photoreception face (photoreception region). Incident light to the photoreception face having a predetermined area is

10   integrated in the space direction and time direction for each pixel, and is converted into a single pixel value for each pixel.

The space-time integration of images will be described with reference to Fig. 5 through Fig. 8.

15   An image sensor images a subject (object) in the real world, and outputs the obtained image data as a result of imagining in increments of single frames. That is to say, the image sensor acquires signals of the actual world 1 which is light reflected off of the subject of the actual

20   world 1, and outputs the data 3.

For example, the image sensor outputs image data of 30 frames per second. In this case, the exposure time of the image sensor can be made to be 1/30 seconds. The exposure time is the time from the image sensor starting conversion

25   of incident light into electric charge, to ending of the

conversion of incident light into electric charge.
Hereafter, the exposure time will also be called shutter
time.

Fig. 5 is a diagram describing an example of a pixel
array on the image sensor. In Fig. 5, A through I denote
individual pixels. The pixels are placed on a plane
corresponding to the image displayed by the image data. A
single detecting element corresponding to a single pixel is
placed on the image sensor. At the time of the image sensor
taking images of the actual world 1, the one detecting
element outputs one pixel value corresponding to the one
pixel making up the image data. For example, the position
in the spatial direction X (X coordinate) of the detecting
element corresponds to the horizontal position on the image
displayed by the image data, and the position in the spatial
direction Y (Y coordinate) of the detecting element
corresponds to the vertical position on the image displayed
by the image data.

Distribution of intensity of light of the actual world
1 has expanse in the three-dimensional spatial directions
and the time direction, but the image sensor acquires light
of the actual world 1 in two-dimensional spatial directions
and the time direction, and generates data 3 representing
the distribution of intensity of light in the two-
dimensional spatial directions and the time direction.

As shown in Fig. 6, the detecting device which is a CCD
for example, converts light cast onto the photoreception
face (photoreception region) (detecting region) into
electric charge during a period corresponding to the shutter
5   time, and accumulates the converted charge. The light is
information (signals) of the actual world 1 regarding which
the intensity is determined by the three-dimensional spatial
position and point-in-time. The distribution of intensity
of light of the actual world 1 can be represented by a
10 function $F(x, y, z, t)$, wherein position x, y, z, in three-
dimensional space, and point-in-time t, are variables.

The amount of charge accumulated in the detecting
device which is a CCD is approximately proportionate to the
intensity of the light cast onto the entire photoreception
15 face having two-dimensional spatial expanse, and the amount
of time that light is cast thereupon. The detecting device
adds the charge converted from the light cast onto the
entire photoreception face, to the charge already
accumulated during a period corresponding to the shutter
20 time. That is to say, the detecting device integrates the
light cast onto the entire photoreception face having a two-
dimensional spatial expanse, and accumulates a change of an
amount corresponding to the integrated light during a period
corresponding to the shutter time. The detecting device can
25 also be said to have an integration effect regarding space

(photoreception face) and time (shutter time).

The charge accumulated in the detecting device is converted into a voltage value by an unshown circuit, the voltage value is further converted into a pixel value such
5   as digital data or the like, and is output as data 3. Accordingly, the individual pixel values output from the image sensor have a value projected on one-dimensional space, which is the result of integrating the portion of the information (signals) of the actual world 1 having time-
10 space expanse with regard to the time direction of the shutter time and the spatial direction of the photoreception face of the detecting device.

That is to say, the pixel value of one pixel is represented as the integration of F(x, y, t). F(x, y, t) is
15 a function representing the distribution of light intensity on the photoreception face of the detecting device. For example, the pixel value P is represented by Expression (1).

$$P = \int_{t_1}^{t_2} \int_{y_1}^{y_2} \int_{x_1}^{x_2} F(x, y, t)\, dx\, dy\, dt$$

$$\ldots (1)$$

In Expression (1), x_1 represents the spatial coordinate
20 at the left-side boundary of the photoreception face of the detecting device (X coordinate). x_2 represents the spatial coordinate at the right-side boundary of the photoreception face of the detecting device (X coordinate). In Expression

(1), y_1 represents the spatial coordinate at the top-side boundary of the photoreception face of the detecting device (Y coordinate). y_2 represents the spatial coordinate at the bottom-side boundary of the photoreception face of the

5 detecting device (Y coordinate). Also, t_1 represents the point-in-time at which conversion of incident light into an electric charge was started. t_2 represents the point-in-time at which conversion of incident light into an electric charge was ended.

10 Note that actually, the gain of the pixel values of the image data output from the image sensor is corrected for the overall frame, for example.

Each of the pixel values of the image data are integration values of the light cast on the photoreception

15 face of each of the detecting elements of the image sensor, and of the light cast onto the image sensor, waveforms of light of the actual world 1 finer than the photoreception face of the detecting element are hidden in the pixel value as integrated values.

20 Hereafter, in the present Specification, the waveform of signals represented with a predetermined dimension as a reference may be referred to simply as waveforms.

Thus, the image of the actual world 1 (light signals) is integrated in the spatial direction and time direction in

25 increments of pixels, so a part of the continuity of the

image of the actual world 1 drops out from the image data,
so another part of the continuity of the image of the actual
world 1 is left in the image data. Or, there may be cases
wherein continuity which has changed from the continuity of

5 the image of the actual world 1 is included in the image
data.

Further description will be made regarding the
integration effect in the spatial direction for an image
taken by an image sensor having integration effects.

10 Fig. 7 is a diagram describing the relation between
incident light to the detecting elements corresponding to
the pixel D through pixel F, and the pixel values. F(x) in
Fig. 7 is an example of a function representing the
distribution of light intensity of the actual world 1,

15 having the coordinate x in the spatial direction X in space
(on the detecting device) as a variable. In other words,
F(x) is an example of a function representing the
distribution of light intensity of the actual world 1, with
the spatial direction Y and time direction constant. In Fig.

20 7, L indicates the length in the spatial direction X of the
photoreception face of the detecting device corresponding to
the pixel D through pixel F.

The pixel value of a single pixel is represented as the
integral of F(x). For example, the pixel value P of the

25 pixel E is represented by Expression (2).

$$P = \int_{x_1}^{x_2} F(x)\, dx$$

...(2)

In Expression (2), x_1 represents the spatial coordinate in the spatial direction X at the left-side boundary of the photoreception face of the detecting device corresponding to

5   the pixel E. x_2 represents the spatial coordinate in the spatial direction X at the right-side boundary of the photoreception face of the detecting device corresponding to the pixel E.

In the same way, further description will be made

10   regarding the integration effect in the time direction for an image taken by an image sensor having integration effects.

Fig. 8 is a diagram for describing the relation between time elapsed, the incident light to a detecting element corresponding to a single pixel, and the pixel value. F(t)

15   in Fig. 8 is a function representing the distribution of light intensity of the actual world 1, having the point-in-time t as a variable. In other words, F(t) is an example of a function representing the distribution of light intensity of the actual world 1, with the spatial direction Y and the

20   spatial direction X constant. T_s represents the shutter time.

The frame #n-1 is a frame which is previous to the frame #n time-wise, and the frame #n+1 is a frame following the frame #n time-wise. That is to say, the frame #n-1,

25   frame #n, and frame #n+1, are displayed in the order of

frame #n-1, frame #n, and frame #n+1.

Note that in the example shown in Fig. 8, the shutter time t_s and the frame intervals are the same.

The pixel value of a single pixel is represented as the integral of F(t). For example, the pixel value P of the pixel of frame #n is represented by Expression (3).

$$P = \int_{t_1}^{t_2} F(t) \, dx$$

$$...(3)$$

In Expression (3), t_1 represents the time at which conversion of incident light into an electric charge was started. t_2 represents the time at which conversion of incident light into an electric charge was ended.

Hereafter, the integration effect in the spatial direction by the sensor 2 will be referred to simply as spatial integration effect, and the integration effect in the time direction by the sensor 2 also will be referred to simply as time integration effect. Also, space integration effects or time integration effects will be simply called integration effects.

Next, description will be made regarding an example of continuity of data included in the data 3 acquired by the image sensor having integration effects.

Fig. 9 is a diagram illustrating a linear object of the actual world 1 (e.g., a fine line), i.e., an example of

distribution of light intensity. In Fig. 9, the position to
the upper side of the drawing indicates the intensity
(level) of light, the position to the upper right side of
the drawing indicates the position in the spatial direction
5   X which is one direction of the spatial directions of the
image, and the position to the right side of the drawing
indicates the position in the spatial direction Y which is
the other direction of the spatial directions of the image.

The image of the linear object of the actual world 1
10 includes predetermined continuity. That is to say, the
image shown in Fig. 9 has continuity in that the cross-
sectional shape (the change in level as to the change in
position in the direction orthogonal to the length
direction), at any arbitrary position in the length
15 direction.

Fig. 10 is a diagram illustrating an example of pixel
values of image data obtained by actual image-taking,
corresponding to the image shown in Fig. 9.

That is to say, Fig. 10 is a model diagram of the image
20 data obtained by imaging, with the image sensor, an image of
a linear object having a diameter shorter than the length L
of the photoreception face of each pixel, and extending in a
direction offset from the array of the pixels of the image
sensor (the vertical or horizontal array of the pixels).
25 The image cast into the image sensor at the time that the

image data shown in Fig. 10 was acquired is an image of the
linear object of the actual world 1 shown in Fig. 9.

In Fig. 10, the position to the upper side of the
drawing indicates the pixel value, the position to the upper

5   right side of the drawing indicates the position in the
spatial direction X which is one direction of the spatial
directions of the image, and the position to the right side
of the drawing indicates the position in the spatial
direction Y which is the other direction of the spatial

10   directions of the image. The direction indicating the pixel
value in Fig. 10 corresponds to the direction of level in
Fig. 9, and the spatial direction X and spatial direction Y
in Fig. 10 also are the same as the directions in Fig. 9.

In the event of taking an image of a linear object

15   having a diameter shorter than the length L of the
photoreception face of each pixel with the image sensor, the
linear object is represented in the image data obtained as a
result of the image-taking as multiple arc shapes (half-
discs) having a predetermined length which are arrayed in a

20   diagonally-offset fashion, in a model representation, for
example. The arc shapes are of approximately the same shape.
One arc shape is formed on one row of pixels vertically, or
is formed on one row of pixels horizontally. For example,
one arc shape shown in Fig. 10 is formed on one row of

25   pixels vertically.

Thus, with the image data taken and obtained by the image sensor for example, the continuity in that the cross-sectional shape in the spatial direction Y at any arbitrary position in the length direction is the same, which the

5   linear object image of the actual world 1 had, is lost. Also, it can be said that the continuity, which the linear object image of the actual world 1 had, has changed into continuity in that arc shapes of the same shape formed on one row of pixels vertically or formed on one row of pixels

10 horizontally are arrayed at predetermined intervals.

Fig. 11 is a diagram illustrating an image in the actual world 1 of an object having a straight edge, and is of a monotone color different from that of the background, i.e., an example of distribution of light intensity. In Fig.

15 11, the position to the upper side of the drawing indicates the intensity (level) of light, the position to the upper right side of the drawing indicates the position in the spatial direction X which is one direction of the spatial directions of the image, and the position to the right side

20 of the drawing indicates the position in the spatial direction Y which is the other direction of the spatial directions of the image.

The image of the object of the actual world 1 which has a straight edge and is of a monotone color different from

25 that of the background, includes predetermined continuity.

That is to say, the image shown in Fig. 11 has continuity in that the cross-sectional shape (the change in level as to the change in position in the direction orthogonal to the edge) is the same at any arbitrary position in the length

5   direction of the edge.

Fig. 12 is a diagram illustrating an example of pixel values of the image data obtained by actual image-taking, corresponding to the image shown in Fig. 11. As shown in Fig. 12, the image data is in a stepped shape, since the

10   image data is made up of pixel values in increments of pixels.

Fig. 13 is a model diagram illustrating the image data shown in Fig. 12.

The model diagram shown in Fig. 13 is a model diagram

15   of image data obtained by taking, with the image sensor, an image of the object of the actual world 1 which has a straight edge and is of a monotone color different from that of the background, and extending in a direction offset from the array of the pixels of the image sensor (the vertical or

20   horizontal array of the pixels). The image cast into the image sensor at the time that the image data shown in Fig. 13 was acquired is an image of the object of the actual world 1 which has a straight edge and is of a monotone color different from that of the background, shown in Fig. 11.

25   In Fig. 13, the position to the upper side of the

drawing indicates the pixel value, the position to the upper

right side of the drawing indicates the position in the

spatial direction X which is one direction of the spatial

directions of the image, and the position to the right side

5   of the drawing indicates the position in the spatial

direction Y which is the other direction of the spatial

directions of the image.   The direction indicating the pixel

value in Fig. 13 corresponds to the direction of level in

Fig. 11, and the spatial direction X and spatial direction Y

10   in Fig. 13 also are the same as the directions in Fig. 11.

In the event of taking an image of an object of the

actual world 1 which has a straight edge and is of a

monotone color different from that of the background with an

image sensor, the straight edge is represented in the image

15   data obtained as a result of the image-taking as multiple

pawl shapes having a predetermined length which are arrayed

in a diagonally-offset fashion, in a model representation,

for example.   The pawl shapes are of approximately the same

shape.   One pawl shape is formed on one row of pixels

20   vertically, or is formed on one row of pixels horizontally.

For example, one pawl shape shown in Fig. 13 is formed on

one row of pixels vertically.

Thus, the continuity of image of the object of the

actual world 1 which has a straight edge and is of a

25   monotone color different from that of the background, in

that the cross-sectional shape is the same at any arbitrary

position in the length direction of the edge, for example,

is lost in the image data obtained by imaging with an image

sensor. Also, it can be said that the continuity, which the

5   image of the object of the actual world 1 which has a

straight edge and is of a monotone color different from that

of the background had, has changed into continuity in that

pawl shapes of the same shape formed on one row of pixels

vertically or formed on one row of pixels horizontally are

10   arrayed at predetermined intervals.

The data continuity detecting unit 101 detects such

data continuity of the data 3 which is an input image, for

example. For example, the data continuity detecting unit

101 detects data continuity by detecting regions having a

15   continuity in a predetermined dimensional direction. For

example, the data continuity detecting unit 101 detects a

region wherein the same arc shapes are arrayed at constant

intervals, such as shown in Fig. 10. Also, for example, the

data continuity detecting unit 101 detects a region wherein

20   the same pawl shapes are arrayed at constant intervals, such

as shown in Fig. 13.

Also, the data continuity detecting unit 101 detects

continuity of the data by detecting angle (gradient) in the

spatial direction, indicating an array of the same shapes.

25   Also, for example, the data continuity detecting unit

101 detects continuity of data by detecting angle (movement) in the space direction and time direction, indicating the array of the same shapes in the space direction and the time direction.

5   Further, for example, the data continuity detecting unit 101 detects continuity in the data by detecting the length of the region having continuity in a predetermined dimensional direction.

Hereafter, the portion of data 3 where the sensor 2 has 10   projected the image of the object of the actual world 1 which has a straight edge and is of a monotone color different from that of the background, will also be called a two-valued edge.

Now, with conventional signal processing, desired high-15   resolution data, for example, is generated from the data 3.

Conversely, with the signal processing by the signal processing device 4, the actual world 1 is estimated from the data 3, and the high-resolution data is generated based on the estimation results. That is to say, the actual world 20   1 is estimated from the data 3, and the high-resolution data is generated based on the estimated actual world 1, taking into consideration the data 3.

In order to generate the high-resolution data from the actual world 1, there is the need to take into consideration 25   the relation between the actual world 1 and the data 3. For

example, how the actual world 1 is projected on the data 3

by the sensor 2 which is a CCD, is taken into consideration.

The sensor 2 which is a CCD has integration properties

as described above. That is to say, one unit of the data 3

5   (e.g., pixel value) can be calculated by integrating a

signal of the actual world 1 with a detection region (e.g.,

photoreception face) of a detection device (e.g., CCD) of

the sensor 2.

Applying this to the high-resolution data, the high-

10   resolution data can be obtained by applying processing,

wherein a virtual high-resolution sensor projects signals of

the actual world 1 to the data 3, to the estimated actual

world 1.

In other words, if the signals of the actual world 1

15   can be estimated from the data 3, one value contained in the

high-resolution data can be obtained by integrating signals

of the actual world 1 for each detection region of the

detecting elements of the virtual high-resolution sensor (in

the time-space direction).

20   For example, in the event that the change in signals of

the actual world 1 are smaller than the size of the

detection region of the detecting elements of the sensor 2,

the data 3 cannot expresses the small changes in the signals

of the actual world 1. Accordingly, high-resolution data

25   indicating small change of the signals of the actual world 1

can be obtained by integrating the signals of the actual
world 1 estimated from the data 3 with each region (in the
time-space direction) that is smaller in comparison with the
change in signals of the actual world 1.

5   That is to say, integrating the signals of the
estimated actual world 1 with the detection region with
regard to each detecting element of the virtual high-
resolution sensor enables the high-resolution data to be
obtained.

10   With the signal processing device 4, the image
generating unit 103 generates the high-resolution data by
integrating the signals of the estimated actual world 1 in
the time-space direction regions of the detecting elements
of the virtual high-resolution sensor, for example.

15   Next, in order to estimate the actual world 1 from the
data 3, at the signal processing device 4, the relationship
between the data 3 and the actual world 1, continuity, and a
spatial or temporal mixture in the data 3 (space mixture or
time mixture), are used.

20   Here, a mixture means a value in the data 3 wherein the
signals of two objects in the actual world 1 are mixed to
yield a single value.

A space mixture means the mixture of the signals of two
objects in the spatial direction due to the spatial

25 integration effects of the sensor 2. Time mixture will be

described later.

The actual world 1 itself is made up of countless events, and accordingly, in order to represent the actual world 1 itself with mathematical expressions, for example,

5   there is the need to have an infinite number of variables. It is impossible to predict all events of the actual world 1 from the data 3.

In the same way, it is impossible to predict all of the signals of the actual world 1 from the data 3.

10   Accordingly, with the signal processing device 4, of the signals of the actual world 1, a portion which has continuity and which can be expressed by the function $f(x, y, z, t)$ is taken note of, and the portion of the signals of the actual world 1 which can be represented by the function

15    $f(x, y, z, t)$ and has continuity is approximated with a model 161 represented by N variables. As shown in Fig. 14, the model 161 is predicted from the M pieces of data 162 in the data 3.

In order to enable the model 161 to be predicted from

20   the M pieces of data 162, first, there is the need to represent the model 161 with N variables based on the continuity, and second, to generate an expression using the N variables which indicates the relation between the model 161 represented by the N variables and the M pieces of data

25   162 based on the integral properties of the sensor 2. Since

the model 161 is represented by the N variables, based on

the continuity, it can be said that the expression using the

N variables that indicates the relation between the model

161 represented by the N variables and the M pieces of data

5   162, describes the relation between the part of the signals

of the actual world 1 having continuity, and the part of the

data 3 having data continuity.

In other words, the part of the signals of the actual

world 1 having continuity, that is approximated by the model

10 161 represented by the N variables, generates data

continuity in the data 3.

The data continuity detecting unit 101 detects the part

of the data 3 where data continuity has been generated by

the part of the signals of the actual world 1 having

15 continuity, and the characteristics of the part where data

continuity has been generated.

For example, as shown in Fig. 15, in an image of the

object of the actual world 1 which has a straight edge and

is of a monotone color different from that of the background,

20 the edge at the position of interest indicated by A in Fig.

15, has a gradient. The arrow B in Fig. 15 indicates the

gradient of the edge. A predetermined edge gradient can be

represented as an angle as to a reference axis or as a

direction as to a reference position. For example, a

25 predetermined edge gradient can be represented as the angle

between the coordinates axis of the spatial direction X and the edge. For example, the predetermined edge gradient can be represented as the direction indicated by the length of the spatial direction X and the length of the spatial

5   direction Y.

At the time that the image of the object of the actual world 1 which has a straight edge and is of a monotone color different from that of the background is obtained at the sensor 2 and the data 3 is output, pawl shapes corresponding

10   to the edge are arrayed in the data 3 at the position corresponding to the position of interest (A) of the edge in the image of the actual world 1, which is indicated by A' in Fig. 15, and pawl shapes corresponding to the edge are arrayed in the direction corresponding to the gradient of

15   the edge of the image in the actual world 1, in the direction of the gradient indicated by B' in Fig. 15.

The model 161 represented with the N variables approximates such a portion of the signals of the actual world 1 generating data continuity in the data 3.

20   At the time of formulating an expression using the N variables indicating the relation between the model 161 represented with the N variables and the M pieces of data 162, the values of part where data continuity is generated in the data 3 are used.

25   In this case, in the data 3 shown in Fig. 16, taking

note of the values where data continuity is generated and
which belong to a mixed region, an expression is formulated
with a value integrating the signals of the actual world 1
as being equal to a value output by the detecting element of

5   the sensor 2.   For example, multiple expressions can be
formulated regarding the multiple values in the data 3 where
data continuity is generated.

In Fig. 16, A denotes the position of interest of the
edge, and A' denotes (the position of) the pixel

10   corresponding to the position (A) of interest of the edge in
the image of the actual world 1.

Now, a mixed region means a region of data in the data
3 wherein the signals for two objects in the actual world 1
are mixed and become one value.   For example, a pixel value

15   wherein, in the image of the object of the actual world 1
which has a straight edge and is of a monotone color
different from that of the background in the data 3, the
image of the object having the straight edge and the image
of the background are integrated, belongs to a mixed region.

20   Fig. 17 is a diagram describing signals for two objects
in the actual world 1 and values belonging to a mixed region,
in a case of formulating an expression.

Fig. 17 illustrates, to the left, signals of the actual
world 1 corresponding to two objects in the actual world 1

25   having a predetermined expansion in the spatial direction X

and the spatial direction Y, which are acquired at the detection region of a single detecting element of the sensor 2. Fig. 17 illustrates, to the right, a pixel value P of a single pixel in the data 3 wherein the signals of the actual

5   world 1 illustrated to the left in Fig. 17 have been projected by a single detecting element of the sensor 2. That is to say, illustrates a pixel value P of a single pixel in the data 3 wherein the signals of the actual world 1 corresponding to two objects in the actual world 1 having

10   a predetermined expansion in the spatial direction X and the spatial direction Y which are acquired by a single detecting element of the sensor 2, have been projected.

L in Fig. 17 represents the level of the signal of the actual world 1 which is shown in white in Fig. 17,

15   corresponding to one object in the actual world 1. R in Fig. 17 represents the level of the signal of the actual world 1 which is shown hatched in Fig. 17, corresponding to the other object in the actual world 1.

Here, the mixture ratio α is the ratio of (the area of)

20   the signals corresponding to the two objects cast into the detecting region of the one detecting element of the sensor 2 having a predetermined expansion in the spatial direction X and the spatial direction Y. For example, the mixture ratio α represents the ratio of area of the level L signals

25   cast into the detecting region of the one detecting element

of the sensor 2 having a predetermined expansion in the
spatial direction X and the spatial direction Y, as to the
area of the detecting region of a single detecting element
of the sensor 2.

5   In this case, the relation between the level L, level R,
and the pixel value P, can be represented by Expression (4).

$$\alpha \times L + f(1-\alpha) \times R = P$$

$$\dots (4)$$

Note that there may be cases wherein the level R may be
10   taken as the pixel value of the pixel in the data 3
positioned to the right side of the pixel of interest, and
there may be cases wherein the level L may be taken as the
pixel value of the pixel in the data 3 positioned to the
left side of the pixel of interest.

15   Also, the time direction can be taken into
consideration in the same way as with the spatial direction
for the mixture ratio α and the mixed region. For example,
in the event that an object in the actual world 1 which is
the object of image-taking, is moving as to the sensor 2,
20   the ratio of signals for the two objects cast into the
detecting region of the single detecting element of the
sensor 2 changes in the time direction. The signals for the
two objects regarding which the ratio changes in the time
direction, that have been cast into the detecting region of
25   the single detecting element of the sensor 2, are projected

into a single value of the data 3 by the detecting element
of the sensor 2.

The mixture of signals for two objects in the time
direction due to time integration effects of the sensor 2
5   will be called time mixture.

The data continuity detecting unit 101 detects regions
of pixels in the data 3 where signals of the actual world 1
for two objects in the actual world 1, for example, have
been projected. The data continuity detecting unit 101
10   detects gradient in the data 3 corresponding to the gradient
of an edge of an image in the actual world 1, for example.

The actual world estimating unit 102 estimates the
signals of the actual world 1 by formulating an expression
using N variables, representing the relation between the
15   model 161 represented by the N variables and the M pieces of
data 162, based on the region of the pixels having a
predetermined mixture ratio α detected by the data
continuity detecting unit 101 and the gradient of the region,
for example, and solving the formulated expression.

20   Description will be made further regarding specific
estimation of the actual world 1.

Of the signals of the actual world represented by the
function $F(x, y, z, t)$ let us consider approximating the
signals of the actual world represented by the function $F(x,$
25   $y, t)$ at the cross-section in the spatial direction Z (the

position of the sensor 2), with an approximation function

f(x, y, t) determined by a position x in the spatial

direction X, a position y in the spatial direction Y, and a

point-in-time t.

5   Now, the detection region of the sensor 2 has an

expanse in the spatial direction X and the spatial direction

Y. In other words, the approximation function f(x, y, t) is

a function approximating the signals of the actual world 1

having an expanse in the spatial direction and time

10   direction, which are acquired with the sensor 2.

Let us say that projection of the signals of the actual

world 1 from the sensor 2 yields a value P(x, y, t) of the

data 3. The value P(x, y, t) of the data 3 is a pixel value

which the sensor 2 which is an image sensor outputs, for

15   example.

Now, in the event that the projection by the sensor 2

can be formulated, the value obtained by projecting the

approximation function f(x, y, t) can be represented as a

projection function S(x, y, t).

20   Obtaining the projection function S(x, y, t) has the

following problems.

First, generally, the function F(x, y, z, t)

representing the signals of the actual world 1 can be a

function with an infinite number of orders.

25   Second, even if the signals of the actual world could

be described as a function, the projection function $S(x, y, t)$ via projection of the sensor 2 generally cannot be determined. That is to say, the action of projection by the sensor 2, in other words, the relation between the input

5 signals and output signals of the sensor 2, is unknown, so the projection function $S(x, y, t)$ cannot be determined.

With regard to the first problem, let us consider expressing the function $f(x, y, t)$ approximating signals of the actual world 1 with the sum of products of the function

10 $f_i(x, y, t)$ which is a describable function(e.g., a function with a finite number of orders) and variables w_i.

Also, with regard to the second problem, formulating projection by the sensor 2 allows us to describe the function $S_i(x, y, t)$ from the description of the function

15 $f_i(x, y, t)$.

That is to say, representing the function $f(x, y, t)$ approximating signals of the actual world 1 with the sum of products of the function $f_i(x, y, t)$ and variables w_i, Expression (5) can be obtained.

$$f(x, y, t) = \sum_{i=1}^{N} w_i f_i(x, y, t)$$

20   ...(5)

For example, as indicated in Expression (6), the relation between the data 3 and the signals of the actual world can be formulated as shown in Expression (7) from

Expression (5) by formulating the projection of the sensor 2.

$$S_i(x, y, t) = \iiint f_i(x, y, t) \, dx \, dy \, dt$$

$$\dots (6)$$

$$P_j(x_j, y_j, t_j) = \sum_{i=1}^{N} w_i S_i(x_j, y_j, t_j)$$

$$\dots (7)$$

In Expression (7), j represents the index of the data.

5   In the event that M data groups (j = 1 through M) common with the N variables w_i (i = 1 through N) exists in Expression (7), Expression (8) is satisfied, so the model 161 of the actual world can be obtained from data 3.

$$N \leq M$$

10 $\dots (8)$

N is the number of variables representing the model 161 approximating the actual world 1. M is the number of pieces of data 162 include in the data 3.

Representing the function f(x, y, t) approximating the

15   actual world 1 signals with Expression (5) allows the variable portion w_i to be handled independently. At this time, i represents the number of variables. Also, the form of the function represented by f_i can be handed independently, and a desired function can be used for f_i.

20   Accordingly, the number N of the variables w_i can be defined without dependence on the function f_i, and the variables w_i can be obtained from the relation between the

number N of the variables w_i and the number of pieces of data M.

That is to say, using the following three allows the actual world 1 to be estimated from the data 3.

5   First, the N variables are determined. That is to say, Expression (5) is determined. This enables describing the actual world 1 using continuity. For example, the signals of the actual world 1 can be described with a model 161 wherein a cross-section is expressed with a polynomial, and

10   the same cross-sectional shape continues in a constant direction.

Second, for example, projection by the sensor 2 is formulated, describing Expression (7). For example, this is formulated such that the results of integration of the

15   signals of the actual world 2 are data 3.

Third, M pieces of data 162 are collected to satisfy Expression (8). For example, the data 162 is collected from a region having data continuity that has been detected with the data continuity detecting unit 101. For example, data

20   162 of a region wherein a constant cross-section continues, which is an example of continuity, is collected.

In this way, the relation between the data 3 and the actual world 1 is described with Expression (5), and M pieces of data 162 are collected, thereby satisfying

25   Expression (8), and the actual world 1 can be estimated.

More specifically, in the event of N = M, the number of variables N and the number of expressions M are equal, so the variables w_i can be obtained by formulating a simultaneous equation.

5   Also, in the event that N < M, various solving methods can be applied. For example, the variables w_i can be obtained by least-square.

Now, the solving method by least-square will be described in detail

10   First, an Expression (9) for predicting data 3 from the actual world 1 will be shown according to Expression (7).

$$P'_j(x_j, y_j, t_j) = \sum_{i=1}^{N} w_i S_i(x_j, y_j, t_j)$$

...(9)

In Expression (9), $P'_j(x_j, y_j, t_j)$ is a prediction value. The sum of squared differences E for the prediction

15   value P' and observed value P is represented by Expression (10).

$$E = \sum_{j=1}^{M} (P_j(x_j, y_j, t_j) - P'_j(x_j, y_j, t_j))^2$$

...(10)

The variables w_i are obtained such that the sum of squared differences E is the smallest. Accordingly, the

20   partial differential value of Expression (10) for each variable w_k is 0. That is to say, Expression (11) holds.

$$\frac{\partial E}{\partial w_k} = -2 \sum_{j=1}^{M} w_i S_k(x_j, y_j, t_j)(P_j(x_j, y_j, t_j) - \sum_{i=1}^{N} w_i S_i(x_j, y_j, t_j)) = 0$$

$$\cdots (11)$$

Expression (11) yields Expression (12).

$$\sum_{j=1}^{M} \left(S_k(x_j, y_j, t_j) \sum_{i=1}^{N} w_i S_i(x_j, y_j, t_j) \right) = \sum_{j=1}^{M} S_k(x_j, y_j, t_j) P_j(x_j, y_j, t_j)$$

$$\cdots (12)$$

When Expression (12) holds with K = 1 through N, the solution by least-square is obtained. The normal equation thereof is shown in Expression (13).

$$\begin{pmatrix} \sum\limits_{j=1}^{M} S_1(j)S_1(j) & \sum\limits_{j=1}^{M} S_1(j)S_2(j) & \cdots & \sum\limits_{j=1}^{M} S_1(j)S_N(j) \\ \sum\limits_{j=1}^{M} S_2(j)S_1(j) & \sum\limits_{j=1}^{M} S_2(j)S_2(j) & \cdots & \sum\limits_{j=1}^{M} S_2(j)S_N(j) \\ \vdots & \vdots & \ddots & \vdots \\ \sum\limits_{j=1}^{M} S_N(j)S_1(j) & \sum\limits_{j=1}^{M} S_N(j)S_2(j) & \cdots & \sum\limits_{j=1}^{M} S_N(j)S_N(j) \end{pmatrix} \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_N \end{pmatrix} = \begin{pmatrix} \sum\limits_{j=1}^{M} S_1(j)P_j(j) \\ \sum\limits_{j=1}^{M} S_2(j)P_j(j) \\ \vdots \\ \sum\limits_{j=1}^{M} S_N(j)P_j(j) \end{pmatrix}$$

$$\cdots (13)$$

Note that in Expression (13), $S_i(x_j, y_j, t_j)$ is described as $S_i(j)$.

$$S_{MAT} = \begin{pmatrix} \sum\limits_{j=1}^{M} S_1(j)S_1(j) & \sum\limits_{j=1}^{M} S_1(j)S_2(j) & \cdots & \sum\limits_{j=1}^{M} S_1(j)S_N(j) \\ \sum\limits_{j=1}^{M} S_2(j)S_1(j) & \sum\limits_{j=1}^{M} S_2(j)S_2(j) & \cdots & \sum\limits_{j=1}^{M} S_2(j)S_N(j) \\ \vdots & \vdots & \ddots & \vdots \\ \sum\limits_{j=1}^{M} S_N(j)S_1(j) & \sum\limits_{j=1}^{M} S_N(j)S_2(j) & \cdots & \sum\limits_{j=1}^{M} S_N(j)S_N(j) \end{pmatrix} \cdots (14)$$

$$W_{MAT} = \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_N \end{pmatrix}$$

$$\ldots(15)$$

$$P_{MAT} = \begin{pmatrix} \sum\limits_{j=1}^{M} S_1(j)P_j(j) \\ \sum\limits_{j=1}^{M} S_2(j)P_j(j) \\ \vdots \\ \sum\limits_{j=1}^{M} S_N(j)P_j(j) \end{pmatrix}$$

$$\ldots(16)$$

From Expression (14) through Expression (16),

5   Expression (13) can be expressed as $S_{MAT}W_{MAT} = P_{MAT}$.

In Expression (13), S_i represents the projection of the

actual world 1.   In Expression (13), P_j represents the data

3.   In Expression (13), w_i represents variables for

describing and obtaining the characteristics of the signals

10   of the actual world 1.

Accordingly, inputting the data 3 into Expression (13)

and obtaining W_{MAT} by a matrix solution or the like enables

the actual world 1 to be estimated.   That is to say, the

actual world 1 can be estimated by computing Expression (17).

15    $$W_{MAT} = S_{MAT}^{-1} P_{MAT}$$

$$\ldots(17)$$

Note that in the event that S_{MAT} is not regular, a

transposed matrix of S_{MAT} can be used to obtain W_{MAT}.

The actual world estimating unit 102 estimates the actual world 1 by, for example, inputting the data 3 into Expression (13) and obtaining W_{MAT} by a matrix solution or the like.

5   Now, an even more detailed example will be described. For example, the cross-sectional shape of the signals of the actual world 1, i.e., the change in level as to the change in position, will be described with a polynomial. Let us assume that the cross-sectional shape of the signals of the

10   actual world 1 is constant, and that the cross-section of the signals of the actual world 1 moves at a constant speed. Projection of the signals of the actual world 1 from the sensor 2 to the data 3 is formulated by three-dimensional integration in the time-space direction of the signals of

15   the actual world 1.

The assumption that the cross-section of the signals of the actual world 1 moves at a constant speed yields Expression (18) and Expression (19).

$$\frac{dx}{dt} = v_x$$

20   ...(18)

$$\frac{dy}{dt} = v_y$$

...(19)

Here, v_x and v_y are constant.

Using Expression (18) and Expression (19), the cross-sectional shape of the signals of the actual world 1 can be represented as in Expression (20).

$$f(x', y') = f(x + v_x t, y + v_y t)$$

$$\ldots (20)$$

Formulating projection of the signals of the actual world 1 from the sensor 2 to the data 3 by three-dimensional integration in the time-space direction of the signals of the actual world 1 yields Expression (21).

$$S(x, y, t) = \int_{x_s}^{x_e} \int_{y_s}^{y_e} \int_{t_s}^{t_e} f(x', y') \, dx \, dy \, dt$$

$$= \int_{x_s}^{x_e} \int_{y_s}^{y_e} \int_{t_s}^{t_e} f(x + v_x t, y + v_y t) \, dx \, dy \, dt$$

$$\ldots (21)$$

In Expression (21), $S(x, y, t)$ represents an integrated value the region from position x_s to position x_e for the spatial direction X, from position y_s to position y_e for the spatial direction Y, and from point-in-time t_s to point-in-time t_e for the time direction t, i.e., the region represented as a space-time cuboid.

Solving Expression (13) using a desired function $f(x', y')$ whereby Expression (21) can be determined enables the signals of the actual world 1 to be estimated.

In the following, we will use the function indicated in Expression (22) as an example of the function $f(x', y')$.

$$f(x', y') = w_1 x' + w_2 y' + w_3$$
$$= w_1(x + v_x t) + w_2(y + v_y t) + w_3 \qquad \ldots (22)$$

That is to say, the signals of the actual world 1 are estimated to include the continuity represented in Expression (18), Expression (19), and Expression (22). This

5 indicates that the cross-section with a constant shape is moving in the space-time direction as shown in Fig. 18.

Substituting Expression (22) into Expression (21) yields Expression (23).

$$S(x, y, t) = \int_{x_s}^{x_e} \int_{y_s}^{y_e} \int_{t_s}^{t_e} f(x + v_x t, y + v_y t)\, dx\, dy\, dt$$

$$= \text{Volume}\left(\frac{w_0}{2}(x_e + x_s + v_x(t_e + t_s))\right.$$

$$\left. + \frac{w_1}{2}(y_e + y_s + v_y(t_e + t_s)) + w_2\right)$$

$$= w_0 S_0(x, y, t) + w_1 S_1(x, y, t) + w_2 S_2(x, y, t) \qquad \ldots (23)$$

10 wherein

Volume $= (x_e - x_s)\ (y_e - y_s)\ (t_e - t_s)$

$S_0(x, y, t) = \text{Volume}/2 \times (x_e + x_s + v_x(t_e + t_s))$

$S_1(x, y, t) = \text{Volume}/2 \times (y_e + y_s + v_y(t_e + t_s))$

$S_2(x, y, t) = 1$

15 holds.

Fig. 19 is a diagram illustrating an example of the M pieces of data 162 extracted from the data 3. For example,

let us say that 27 pixel values are extracted as the data
162, and that the extracted pixel values are $P_j(x, y, t)$.
In this case, j is 0 through 26.

In the example shown in Fig. 19, in the event that the
pixel value of the pixel corresponding to the position of
interest at the point-in-time t which is n is $P_{13}(x, y, t)$,
and the direction of array of the pixel values of the pixels
having the continuity of data (e.g., the direction in which
the same-shaped pawl shapes detected by the data continuity
detecting unit 101 are arrayed) is a direction connecting
$P_4(x, y, t)$, $P_{13}(x, y, t)$, and $P_{22}(x, y, t)$, the pixel values
$P_9(x, y, t)$ through $P_{17}(x, y, t)$ at the point-in-time t which
is n, the pixel values $P_0(x, y, t)$ through $P_8(x, y, t)$ at the
point-in-time t which is n - 1 which is earlier in time than
n, and the pixel values $P_{18}(x, y, t)$ through $P_{26}(x, y, t)$ at
the point-in-time t which is n + 1 which is later in time
than n, are extracted.

Now, the region regarding which the pixel values, which
are the data 3 output from the image sensor which is the
sensor 2, have been obtained, have a time-direction and two-
dimensional spatial direction expansion. Now, for example,
the center of gravity of the cuboid corresponding to the
pixel values (the region regarding which the pixel values
have been obtained) can be used as the position of the pixel
in the space-time direction.

Generating Expression (13) from the 27 pixel values $P_0(x, y, t)$ through $P_{26}(x, y, t)$ and from Expression (23), and obtaining W, enables the actual world 1 to be estimated.

In this way, the actual world estimating unit 102

5   generates Expression (13) from the 27 pixel values $P_0(x, y, t)$ through $P_{26}(x, y, t)$ and from Expression (23), and obtains W, thereby estimating the signals of the actual world 1.

Note that a Gaussian function, a sigmoid function, or the like, can be used for the function $f_i(x, y, t)$.

10   An example of processing for generating high-resolution data with even higher resolution, corresponding to the data 3, from the estimated actual world 1 signals, will be described with reference to Fig. 20 through Fig. 23.

As shown in Fig. 20, the data 3 has a value wherein

15   signals of the actual world 1 are integrated in the time direction and two-dimensional spatial directions. For example, a pixel value which is data 3 that has been output from the image sensor which is the sensor 2 has a value wherein the signals of the actual world 1, which is light

20   cast into the detecting device, are integrated by the shutter time which is the detection time in the time direction, and integrated by the photoreception region of the detecting element in the spatial direction.

Conversely, as shown in Fig. 21, the high-resolution

25   data with even higher resolution in the spatial direction is

generated by integrating the estimated actual world 1 signals in the time direction by the same time as the detection time of the sensor 2 which has output the data 3, and also integrating in the spatial direction by a region

5   narrower in comparison with the photoreception region of the detecting element of the sensor 2 which has output the data 3.

Note that at the time of generating the high-resolution data with even higher resolution in the spatial direction,

10   the region where the estimated signals of the actual world 1 are integrated can be set completely disengaged from photoreception region of the detecting element of the sensor 2 which has output the data 3. For example, the high-resolution data can be provided with resolution which is

15   that of the data 3 magnified in the spatial direction by an integer, of course, and further, can be provided with resolution which is that of the data 3 magnified in the spatial direction by a rational number such as 5/3 times, for example.

20   Also, as shown in Fig. 22, the high-resolution data with even higher resolution in the time direction is generated by integrating the estimated actual world 1 signals in the spatial direction by the same region as the photoreception region of the detecting element of the sensor

25   2 which has output the data 3, and also integrating in the

time direction by a time shorter than the detection time of
the sensor 2 which has output the data 3.

Note that at the time of generating the high-resolution
data with even higher resolution in the time direction, the
5   time by which the estimated signals of the actual world 1
are integrated can be set completely disengaged from shutter
time of the detecting element of the sensor 2 which has
output the data 3. For example, the high-resolution data
can be provided with resolution which is that of the data 3
10 magnified in the time direction by an integer, of course,
and further, can be provided with resolution which is that
of the data 3 magnified in the time direction by a rational
number such as 7/4 times, for example.

High-resolution data with movement blurring removed is
15 generated by integrating the estimated actual world 1
signals only in the spatial direction and not in the time
direction.

Further, as shown in Fig. 23, high-resolution data with
higher resolution in the time direction and space direction
20 is generated by integrating the estimated actual world 1
signals in the spatial direction by a region narrower in
comparison with the photoreception region of the detecting
element of the sensor 2 which has output the data 3, and
also integrating in the time direction by a time shorter in
25 comparison with the detection time of the sensor 2 which has

output the data 3.

In this case, the region and time for integrating the estimated actual world 1 signals can be set completely unrelated to the photoreception region and shutter time of
5   the detecting element of the sensor 2 which has output the data 3.

Thus, the image generating unit 103 generates data with higher resolution in the time direction or the spatial direction, by integrating the estimated actual world 1
10 signals by a desired space-time region, for example.

Accordingly, data which is more accurate with regard to the signals of the actual world 1, and which has higher resolution in the time direction or the space direction, can be generated by estimating the signals of the actual world 1.
15   Fig. 24 through Fig. 28 illustrate an example of an input image and an example of the results of processing with the signal processing device 4 used for signal processing.

Fig. 24 is a diagram illustrating an original image of an input image (equivalent to light signals of the actual
20 world 1). Fig. 25 is a diagram illustrating an example of an input image. The input image shown in Fig. 25 is an image generated by taking the average value of pixel values of pixels belonging to blocks made up of 2 by 2 pixels of the image shown in Fig. 24, as the pixel value of a single
25 pixel. That is to say, the input image is an image obtained

by applying spatial direction integration to the image shown
in Fig. 24, imitating the integrating properties of the
sensor.

The original image shown in Fig. 24 contains an image

5   of a fine line inclined at approximately 5 degrees in the
clockwise direction from the vertical direction. In the
same way, the input image shown in Fig. 25 contains an image
of a fine line inclined at approximately 5 degrees in the
clockwise direction from the vertical direction.

10   Fig. 26 is a diagram illustrating an image obtained by
applying conventional class classification adaptation
processing to the input image shown in Fig. 25. Now, class
classification processing is made up of class classification
processing and adaptation processing, wherein the data is

15   classified based on the nature thereof by the class
classification adaptation processing, and subjected to
adaptation processing for each class. In the adaptation
processing, a low-image quality or standard image quality
image, for example, is converted into a high image quality

20   image by being subjected to mapping (mapping) using a
predetermined tap coefficient.

That is to say, with adaptation processing, first data
is converted into second data by being mapped (mapping)
using a predetermined tap coefficient.

25   Now, adaptation processing will be described with

regard to a mapping method using the tap coefficient,
wherein for example, a linear combination model is used, and
also a low-resolution image or standard resolution SD
(Standard Definition) image obtained by filtering a high-

5   resolution HD (High Definition) image with a low-pass filter
is used as the first data, and the HD image used for
obtaining the SD image is used as the second data.

Now, under the above-described conditions, an HD pixel
y making up the HD image can be obtained with the following

10   linear Expression (linear combination) using multiple SD
pixels extracted from SD pixels making up the SD image, as a
prediction tap for predicting the HD image, and the tap
coefficient.

$$y = \sum_{n=1}^{N} w_n x_n$$

...(24)

15   Wherein, in Expression (24), x_n represents the pixel
value of the n'th pixel in the SD image, making up a
prediction tap regarding the HD pixel y, and w_n represents
the n'th tap coefficient to be multiplied by (the pixel
value of) the n'th SD pixel. Note that in Expression (24),

20   a prediction tap is made up of an N number of SD pixels x_1,
x_2, $\cdots$, x_N.

Now, the pixel value y of the HD pixel can be obtained
by a quadratic expression or higher, instead of the linear

expression shown in Expression (24).

Now, in the HD image, saying that y_k represents the true value of (the pixel value of) the k'th HD pixel, and y_k' represents a prediction value of the true value y_k obtained by Expression (24), the prediction error e_k thereof is as expressed in the following Expression, for example.

$$e_k = y_k - y_k'$$

$$\ldots (25)$$

The prediction value y_k' in Expression (25) is obtained according to Expression (24), so substituting the y_k' in Expression (25) according Expression (24) yields the following Expression.

$$e_k = y_k - \left(\sum_{n=1}^{N} w_n x_{n,k} \right)$$

$$\ldots (26)$$

Wherein, in Expression (26), $X_{n,k}$ represents the n'th SD pixel making up the prediction tap for the k'th HD pixel.

While a tap coefficient w_n wherein the prediction error e_k is 0 in Expression (26) is optimal for predicting the HD pixel, obtaining such a tap coefficient w_n for all HD pixels is generally difficult.

Accordingly, as a rule representing the tap coefficient w_n as being optimal, employing the least-square method for example, means that the optimal tap coefficient w_n can be obtained by minimizing the summation E of squared errors

represented in the following Expression for example, as a statistical error.

$$E = \sum_{k=1}^{K} e_k^2$$

$$\ldots(27)$$

Wherein, in Expression (27), K represents the number of samples of sets made up of an HD pixel y_k and SD pixels $X_{1,k}$, $X_{2,k}$, $\cdots$, $X_{N,k}$ making up a prediction tap regarding that HD pixel y_k.

The tap coefficient W_n which makes the summation E of squared errors in Expression (27) smallest (the minimum) is such that the partial differentiation of the summation E by the tap coefficient w_n yields 0. Accordingly, the following Expression must be satisfied.

$$\frac{\partial E}{\partial w_n} = e_1 \frac{\partial e_1}{\partial w_n} + e_2 \frac{\partial e_2}{\partial w_n} + \cdots + e_k \frac{\partial e_{k2}}{\partial w_n} = 0 \quad (n=1, 2, \cdots, N)$$

$$\ldots(28)$$

Now, partial differentiation of the above Expression (26) by the tap coefficient w_n yields the following Expression.

$$\frac{\partial e_k}{\partial w_1} = -X_{1,k}, \frac{\partial e_k}{\partial w_2} = -X_{2,k}, \cdots, \frac{\partial e_k}{\partial w_N} = -X_{N,k}, \quad (k=1, 2, \cdots, K)$$

$$\ldots(29)$$

Expressions (28) and (29) yield the following Expression.

$$\sum_{k=1}^{k} e_k X_{1,k} = 0, \sum_{k=1}^{k} e_k X_{2,k} = 0, \cdots \sum_{k=1}^{k} e_k X_{N,k} = 0$$

$$\ldots(30)$$

Substituting Expression (26) for e_k in Expression (30) allows Expression (30) to be expressed in the form of the

5   normal equation in Expression (31).

$$
\begin{bmatrix}
(\sum_{k=1}^{k} x_{1,k}x_{1,k}) & (\sum_{k=1}^{k} x_{1,k}x_{2,k}) & \cdots & (\sum_{k=1}^{k} x_{1,k}x_{N,k}) \\
(\sum_{k=1}^{k} x_{2,k}x_{1,k}) & (\sum_{k=1}^{k} x_{2,k}x_{2,k}) & \cdots & (\sum_{k=1}^{k} x_{2,k}x_{N,k}) \\
\vdots & \vdots & \ddots & \vdots \\
(\sum_{k=1}^{k} x_{N,k}x_{1,k}) & (\sum_{k=1}^{k} x_{N,k}x_{2,k}) & \cdots & (\sum_{k=1}^{k} x_{N,k}x_{N,k})
\end{bmatrix}
\begin{bmatrix}
w_1 \\ w_2 \\ \vdots \\ w_N
\end{bmatrix}
=
\begin{bmatrix}
(\sum_{k=1}^{k} x_{1,k}y_k) \\
(\sum_{k=1}^{k} x_{2,k}y_k) \\
\vdots \\
(\sum_{k=1}^{k} x_{N,k}y_k)
\end{bmatrix}
$$

$$\ldots(31)$$

Preparing a certain number of sets of the HD pixel y_k and SD pixels $x_{n,k}$ allows as many of the normal equations in Expression (31) to be formulated as the number of tap

10   coefficients w_n to be obtained, and solving Expression (31) allows optimal tap coefficients w_n to be obtained. Note that sweeping (Gauss-Jordan elimination) or the like, for example, can be used for solving Expression (31).

As described above, adaptation processing involves

15   taking a great number of HD pixels y_1, y_2, $\cdots$, y_K as tutor data to serve as a tutor for learning for tap coefficients, and also taking SD pixels $X_{1,k}$, $X_{2,k}$, $\cdots$, $X_{N,k}$ making up a prediction tap regarding each HD pixel y_k as student data to

serve as a student for learning for tap coefficients, and solving Expression (31), thereby performing learning for obtaining an optimal tap coefficient w_n, and further using the optimal tap coefficient w_n to perform mapping

5 (conversion) of an SD image into an HD image according to Expression (24).

Now, for the SD pixels $X_{1,k}$, $X_{2,k}$, $\cdots$, $X_{N,k}$ making up the prediction tap regarding the HD pixels y_k, an SD pixel close to a position on the SD image corresponding to the HD pixel

10 y_k, either spatially or temporally, can be used.

Also, with class classification adaptation processing, learning of the tap coefficient w_n and mapping using the tap coefficient w_n are performed by class. With class classification adaptation processing, class classification

15 processing is performed with regard to the HD pixel y_k of interest, and learning of the tap coefficient w_n and mapping using the tap coefficient w_n are performed for each class obtained by the class classification processing.

An example of class classification processing with

20 regard to the HD pixel y_k is to extract multiple SD pixels from the SD image to serve as a class tap used for class classification of the HD pixel y_k, and to perform M-bit ADRC (Adaptive Dynamic Range Coding) using the class tap made up of the multiple SD pixels.

25 In M-bit ADRC processing, the maximum value MAX and

minimum value MIN of the SD pixels making up the class tap
are detected, DR = MAX - MIN is set as a local dynamic range,
and the SD pixels making up the class tap are re-quantized
into K bits, based on this dynamic range DR. That is to say,

5   the minimum value MIN is subtracted from the SD pixels
making up the class tap, and the subtraction value is
divided by $DR/2^K$ (quantized). Accordingly, in the event
that a class tap is subjected to 1-bit ADRC processing for
example, each SD pixel making up the class tap is one bit.

10   In this case, a bit string obtained by arraying in a
predetermined order the 1-bit pixel values regarding each SD
pixel making up the class tap that have been obtained as
described above is output as ADRC code, and the ADRC code is
taken as a class code representing the class.

15   Note that class classification adaptation processing
differs from simple interpolation processing or the like,
for example, in that components not included in the SD image
but are included in the HD image are reproduced. That is to
say, with class classification adaptation processing, it

20   would seem by looking at Expression (24) alone that this is
the same as interpolation processing using a so-called
interpolation filter, but the tap coefficient w_n which is
equivalent to the tap coefficient of the interpolation
filter has been obtained by learning using an HD image

25   serving as tutor data and an SD image serving as student

data, so the component contained in the HD image can be
reproduced.

Now, tap coefficients w_n which perform various types of
conversion can be obtained in the tap coefficient w_n

5 learning, depending on what sort of combination of tutor
data y and student data x is employed.

That is to say, in a case of taking a high-resolution
HD image as the tutor data y and taking an SD image wherein
the resolution of the HD image has been deteriorated as the

10 student data x, for example, a tap coefficient w_n for
mapping an image into an image with the resolution improved,
can be obtained. Further, in a case of taking an HD image
as the tutor data y and taking an SD image wherein the
number of pixels of the HD image has been reduced as the

15 student data x, for example, a tap coefficient w_n for
mapping an image into an image with an increased number of
pixels making up the image, can be obtained.

Fig. 26 is an image obtained by subjecting the input
image shown in Fig. 25 to mapping by the class

20 classification adaptation processing such as described above.
It can be understood in the image shown in Fig. 26 that the
image of the fine line is different to that of the original
image in Fig. 24.

Fig. 27 is a diagram illustrating the results of

25 detecting the fine line regions from the input image shown

in the example in Fig. 25, by the data continuity detecting

unit 101. In Fig. 27, the white region indicates the fine

line region, i.e., the region wherein the arc shapes shown

in Fig. 10 are arrayed.

5   Fig. 28 is a diagram illustrating an example of the

output image obtained by performing signal processing at the

signal processing device 4, with the image shown in Fig. 25

as the input image. As shown in Fig. 28, the signals

processing device 4 yields an image closer to the fine line

10   image of the original image shown in Fig. 24.

Fig. 29 is a flowchart for describing the processing of

signals with the signal processing device 4.

In step S101, the data continuity detecting unit 101

executes the processing for detecting continuity. The data

15   continuity detecting unit 101 detects data continuity

contained in the input image which is the data 3, and

supplies the data continuity information indicating the

detected data continuity to the actual world estimating unit

102 and the image generating unit 103.

20   The data continuity detecting unit 101 detects the

continuity of data corresponding to the continuity of the

signals of the actual world. In the processing in step S101,

the continuity of data detected by the data continuity

detecting unit 101 is either part of the continuity of the

25   image of the actual world 1 contained in the data 3, or

continuity which has changed from the continuity of the signals of the actual world 1.

For example, the data continuity detecting unit 101 detects the data continuity by detecting a region having a

5 continuity in a predetermined dimensional direction. Also, for example, the data continuity detecting unit 101 detects data continuity by detecting angle (gradient) in the spatial direction indicating the array of the same shape.

Details of the continuity detecting processing in step

10 S101 will be described later.

Note that the data continuity information can be used as features, indicating the characteristics of the data 3.

In step S102, the actual world estimating unit 102 executes processing for estimating the actual world. That

15 is to say, the actual world estimating unit 102 estimates the signals of the actual world based on the input image and the data continuity information supplied from the data continuity detecting unit 101. In the processing in step S102 for example, the actual world estimating unit 102

20 estimates the signals of the actual world 1 by predicting a model 161 approximating (describing) the actual world 1. The actual world estimating unit 102 supplies the actual world estimation information indicating the estimated signals of the actual world 1 to the image generating unit

25 103.

For example, the actual world estimating unit 102
estimates the actual world 1 signals by predicting the width
of the linear object. Also, for example, the actual world
estimating unit 102 estimates the actual world 1 signals by
5   predicting a level indicating the color of the linear object.

Details of processing for estimating the actual world
in step S102 will be described later.

Note that the actual world estimation information can
be used as features, indicating the characteristics of the
10 data 3.

In step S103, the image generating unit 103 performs
image generating processing, and the processing ends. That
is to say, the image generating unit 103 generates an image
based on the actual world estimation information, and
15 outputs the generated image. Or, the image generating unit
103 generates an image based on the data continuity
information and actual world estimation information, and
outputs the generated image.

For example, in the processing in step S103, the image
20 generating unit 103 integrates the estimated real world
light in the spatial direction, based on the actual world
estimated information, thereby generating an image with
higher resolution in the spatial direction in comparison
with the input image, and outputs the generated image. For
25 example, the image generating unit 103 integrates estimated

real world light in the time-space direction, based on the
actual world estimated information, hereby generating an
image with higher resolution in the time direction and the
spatial direction in comparison with the input image, and
5   outputs the generated image. The details of the image
generating processing in step S103 will be described later.

Thus, the signal processing device 4 detects data
continuity from the data 3, and estimates the actual world 1
from the detected data continuity. The signal processing
10   device 4 then generates signals closer approximating the
actual world 1 based on the estimated actual world 1.

As described above, in the event of performing the
processing for estimating signals of the real world,
accurate and highly-precise processing results can be
15   obtained.

Also, in the event that first signals which are real
world signals having first dimensions are projected, the
continuity of data corresponding to the lost continuity of
the real world signals is detected for second signals of
20   second dimensions, having a number of dimensions fewer than
the first dimensions, from which a part of the continuity of
the signals of the real world has been lost, and the first
signals are estimated by estimating the lost real world
signals continuity based on the detected data continuity,
25   accurate and highly-precise processing results can be

obtained as to the events in the real world.

Next, the details of the configuration of the data continuity detecting unit 101 will be described.

Fig. 30 is a block diagram illustrating the

5   configuration of the data continuity detecting unit 101.

Upon taking an image of an object which is a fine line, the data continuity detecting unit 101, of which the configuration is shown in Fig. 30, detects the continuity of data contained in the data 3, which is generated from the

10 continuity in that the cross-sectional shape which the object has is the same. That is to say, the data continuity detecting unit 101 of the configuration shown in Fig. 30 detects the continuity of data contained in the data 3, which is generated from the continuity in that the change in

15 level of light as to the change in position in the direction orthogonal to the length-wise direction is the same at an arbitrary position in the length-wise direction, which the image of the actual world 1 which is a fine line, has.

More specifically, the data continuity detecting unit

20 101 of which configuration is shown in Fig. 30 detects the region where multiple arc shapes (half-disks) having a predetermined length are arrayed in a diagonally-offset adjacent manner, within the data 3 obtained by taking an image of a fine line with the sensor 2 having spatial

25 integration effects.

The data continuity detecting unit 101 extracts the portions of the image data (hereafter referred to as con-continuity component) other than the portion of the image data where the image of the fine line having data continuity

5 has been projected (hereafter, the portion of the image data where the image of the fine line having data continuity has been projected will also be called continuity component, and the other portions will be called non- continuity component), from an input image which is the data 3, detects the pixels

10 where the image of the fine line of the actual world 1 has been projected, from the extracted non-continuity component and the input image, and detects the region of the input image made up of pixels where the image of the fine line of the actual world 1 has been projected.

15 A non-continuity component extracting unit 201 extracts the non-continuity component from the input image, and supplies the non-continuity component information indicating the extracted non-continuity component to a peak detecting unit 202 and a monotonous increase/decrease detecting unit

20 203 along with the input image.

For example, as shown in Fig. 31, in the event that an image of the actual world 1 wherein a fine line exists in front of a background with an approximately constant light level is projected on the data 3, the non-continuity

25 component extracting unit 201 extracts the non-continuity

component which is the background, by approximating the background in the input image which is the data 3, on a plane, as shown in Fig. 32. In Fig. 32, the solid line indicates the pixel values of the data 3, and the dotted line illustrates the approximation values indicated by the plane approximating the background. In Fig. 32, A denotes the pixel value of the pixel where the image of the fine line has been projected, and the PL denotes the plane approximating the background.

In this way, the pixel values of the multiple pixels at the portion of the image data having data continuity are discontinuous as to the non-continuity component.

The non-continuity component extracting unit 201 detects the discontinuous portion of the pixel values of the multiple pixels of the image data which is the data 3, where an image which is light signals of the actual world 1 has been projected and a part of the continuity of the image of the actual world 1 has been lost.

Details of the processing for extracting the non-continuity component with the non-continuity component extracting unit 201 will be described later.

The peak detecting unit 202 and the monotonous increase/decrease detecting unit 203 remove the non-continuity component from the input image, based on the non-continuity component information supplied from the non-

continuity component extracting unit 201. For example, the peak detecting unit 202 and the monotonous increase/decrease detecting unit 203 remove the non-continuity component from the input image by setting the pixel values of the pixels of

5   the input image where only the background image has been projected, to 0. Also, for example, the peak detecting unit 202 and the monotonous increase/decrease detecting unit 203 remove the non-continuity component from the input image by subtracting values approximated by the plane PL from the

10   pixel values of each pixel of the input image.

Since the background can be removed from the input image, the peak detecting unit 202 through continuousness detecting unit 204 can process only the portion of the image data where the fine line has be projected, thereby further

15   simplifying the processing by the peak detecting unit 202 through the continuousness detecting unit 204.

Note that the non-continuity component extracting unit 201 may supply image data wherein the non-continuity component has been removed from the input image, to the peak

20   detecting unit 202 and the monotonous increase/decrease detecting unit 203.

In the example of processing described below, the image data wherein the non-continuity component has been removed from the input image, i.e., image data made up from only

25   pixel containing the continuity component, is the object.

Now, description will be made regarding the image data upon which the fine line image has been projected, which the peak detecting unit 202 through continuousness detecting unit 204 are to detect.

5   In the event that there is no optical LPF, the cross-dimensional shape in the spatial direction Y (change in the pixel values as to change in the position in the spatial direction) of the image data upon which the fine line image has been projected as shown in Fig. 31 can be thought to be

10   the trapezoid shown in Fig. 33, or the triangle shown in Fig. 34, from the spatial; integration effects of the image sensor which is the sensor 2. However, ordinary image sensors have an optical LPF with the image sensor obtaining the image which has passed through the optical LPF and

15   projects the obtained image on the data 3, so in reality, the cross-dimensional shape of the image data with fine lines in the spatial direction Y has a shape resembling Gaussian distribution, as shown in Fig. 35.

The peak detecting unit 202 through continuousness

20   detecting unit 204 detect a region made up of pixels upon which the fine line image has been projected wherein the same cross-sectional shape (change in the pixel values as to change in the position in the spatial direction) is arrayed in the vertical direction in the screen at constant

25   intervals, and further, detect a region made up of pixels

upon which the fine line image has been projected which is a
region having data continuity, by detecting regional
connection corresponding to the length-wise direction of the
fine line of the actual world 1. That is to say, the peak

5   detecting unit 202 through continuousness detecting unit 204
detect regions wherein arc shapes (half-disc shapes) are
formed on a single vertical row of pixels in the input image,
and determine whether or not the detected regions are
adjacent in the horizontal direction, thereby detecting

10   connection of regions where arc shapes are formed,
corresponding to the length-wise direction of the fine line
image which is signals of the actual world 1.

Also, the peak detecting unit 202 through
continuousness detecting unit 204 detect a region made up of

15   pixels upon which the fine line image has been projected
wherein the same cross-sectional shape is arrayed in the
horizontal direction in the screen at constant intervals,
and further, detect a region made up of pixels upon which
the fine line image has been projected which is a region

20   having data continuity, by detecting connection of detected
regions corresponding to the length-wise direction of the
fine line of the actual world 1. That is to say, the peak
detecting unit 202 through continuousness detecting unit 204
detect regions wherein arc shapes are formed on a single

25   horizontal row of pixels in the input image, and determine

whether or not the detected regions are adjacent in the vertical direction, thereby detecting connection of regions where arc shapes are formed, corresponding to the length- wise direction of the fine line image, which is signals of the actual world 1.

5

First, description will be made regarding processing for detecting a region of pixels upon which the fine line image has been projected wherein the same arc shape is arrayed in the vertical direction in the screen at constant

10 intervals.

The peak detecting unit 202 detects a pixel having a pixel value greater than the surrounding pixels, i.e., a peak, and supplies peak information indicating the position of the peak to the monotonous increase/decrease detecting

15 unit 203. In the event that pixels arrayed in a single vertical direction row in the screen are the object, the peak detecting unit 202 compares the pixel value of the pixel position upwards in the screen and the pixel value of the pixel position downwards in the screen, and detects the

20 pixel with the greater pixel value as the peak. The peak detecting unit 202 detects one or multiple peaks from a single image, e.g., from the image of a single frame.

A single screen contains frames or fields. This holds true in the following description as well.

25

For example, the peak detecting unit 202 selects a

pixel of interest from pixels of an image of one frame which have not yet been taken as pixels of interest, compares the pixel value of the pixel of interest with the pixel value of the pixel above the pixel of interest, compares the pixel

5   value of the pixel of interest with the pixel value of the pixel below the pixel of interest, detects a pixel of interest which has a greater pixel value than the pixel value of the pixel above and a greater pixel value than the pixel value of the pixel below, and takes the detected pixel

10 of interest as a peak. The peak detecting unit 202 supplies peak information indicating the detected peak to the monotonous increase/decrease detecting unit 203.

There are cases wherein the peak detecting unit 202 does not detect a peak. For example, in the event that the

15 pixel values of all of the pixels of an image are the same value, or in the event that the pixel values decrease in one or two directions, no peak is detected. In this case, no fine line image has been projected on the image data.

The monotonous increase/decrease detecting unit 203

20 detects a candidate for a region made up of pixels upon which the fine line image has been projected wherein the pixels are vertically arrayed in a single row as to the peak detected by the peak detecting unit 202, based upon the peak information indicating the position of the peak supplied

25 from the peak detecting unit 202, and supplies the region

information indicating the detected region to the
continuousness detecting unit 204 along with the peak
information.

More specifically, the monotonous increase/decrease

5   detecting unit 203 detects a region made up of pixels having
pixel values monotonously decreasing with reference to the
peak pixel value, as a candidate of a region made up of
pixels upon which the image of the fine line has been
projected. Monotonous decrease means that the pixel values

10 of pixels which are farther distance-wise from the peak are
smaller than the pixel values of pixels which are closer to
the peak.

Also, the monotonous increase/decrease detecting unit
203 detects a region made up of pixels having pixel values

15 monotonously increasing with reference to the peak pixel
value, as a candidate of a region made up of pixels upon
which the image of the fine line has been projected.
Monotonous increase means that the pixel values of pixels
which are farther distance-wise from the peak are greater

20 than the pixel values of pixels which are closer to the peak.

In the following, the processing regarding regions of
pixels having pixel values monotonously increasing is the
same as the processing regarding regions of pixels having
pixel values monotonously decreasing, so description thereof

25 will be omitted. Also, with the description regarding

processing for detecting a region of pixels upon which the fine line image has been projected wherein the same arc shape is arrayed horizontally in the screen at constant intervals, the processing regarding regions of pixels having

5   pixel values monotonously increasing is the same as the processing regarding regions of pixels having pixel values monotonously decreasing, so description thereof will be omitted.

For example, the monotonous increase/decrease detecting

10 unit 203 obtains pixel values of each of the pixels in a vertical row as to a peak, the difference as to the pixel value of the pixel above, and the difference as to the pixel value of the pixel below. The monotonous increase/decrease detecting unit 203 then detects a region wherein the pixel

15 value monotonously decreases by detecting pixels wherein the sign of the difference changes.

Further, the monotonous increase/decrease detecting unit 203 detects, from the region wherein pixel values monotonously decrease, a region made up of pixels having

20 pixel values with the same sign as that of the pixel value of the peak, with the sign of the pixel value of the peak as a reference, as a candidate of a region made up of pixels upon which the image of the fine line has been projected.

For example, the monotonous increase/decrease detecting

25 unit 203 compares the sign of the pixel value of each pixel

with the sign of the pixel value of the pixel above and sign of the pixel value of the pixel below, and detects the pixel where the sign of the pixel value changes, thereby detecting a region of pixels having pixel values of the same sign as

5   the peak within the region where pixel values monotonously decrease.

Thus, the monotonous increase/decrease detecting unit 203 detects a region formed of pixels arrayed in a vertical direction wherein the pixel values monotonously decrease as

10 to the peak and have pixels values of the same sign as the peak.

Fig. 36 is a diagram describing processing for peak detection and monotonous increase/decrease region detection, for detecting the region of pixels wherein the image of the

15 fine line has been projected, from the pixel values as to a position in the spatial direction Y.

In Fig. 36 through Fig. 38, P represents a peak. In the description of the data continuity detecting unit 101 of which the configuration is shown in Fig. 30, P represents a

20 peak.

The peak detecting unit 202 compares the pixel values of the pixels with the pixel values of the pixels adjacent thereto in the spatial direction Y, and detects the peak P by detecting a pixel having a pixel value greater than the

25 pixel values of the two pixels adjacent in the spatial

direction Y.

The region made up of the peak P and the pixels on both sides of the peak P in the spatial direction Y is a monotonous decrease region wherein the pixel values of the

5   pixels on both sides in the spatial direction Y monotonously decrease as to the pixel value of the peak P. In Fig. 36, the arrow denoted A and the arrow denoted by B represent the monotonous decrease regions existing on either side of the peak P.

10   The monotonous increase/decrease detecting unit 203 obtains the difference between the pixel values of each pixel and the pixel values of the pixels adjacent in the spatial direction Y, and detects pixels where the sign of the difference changes. The monotonous increase/decrease

15   detecting unit 203 takes the boundary between the detected pixel where the sign of the difference changes and the pixel immediately prior thereto (on the peak P side) as the boundary of the fine line region made up of pixels where the image of the fine line has been projected.

20   In Fig. 36, the boundary of the fine line region which is the boundary between the pixel where the sign of the difference changes and the pixel immediately prior thereto (on the peak P side) is denoted by C.

Further, the monotonous increase/decrease detecting

25   unit 203 compares the sign of the pixel values of each pixel

with the pixel values of the pixels adjacent thereto in the spatial direction Y, and detects pixels where the sign of the pixel value changes in the monotonous decrease region. The monotonous increase/decrease detecting unit 203 takes

5   the boundary between the detected pixel where the sign of the pixel value changes and the pixel immediately prior thereto (on the peak P side) as the boundary of the fine line region.

In Fig. 36, the boundary of the fine line region which

10   is the boundary between the pixel where the sign of the pixel value changes and the pixel immediately prior thereto (on the peak P side) is denoted by D.

As shown in Fig. 36, the fine line region F made up of pixels where the image of the fine line has been projected

15   is the region between the fine line region boundary C and the fine line region boundary D.

The monotonous increase/decrease detecting unit 203 obtains a fine line region F which is longer than a predetermined threshold value, from fine line regions F made

20   up of such monotonous increase/decrease regions, i.e., a fine line region F having a greater number of pixels than the threshold value. For example, in the event that the threshold value is 3, the monotonous increase/decrease detecting unit 203 detects a fine line region F including 4

25   or more pixels.

Further, the monotonous increase/decrease detecting
unit 203 compares the pixel value of the peak P, the pixel
value of the pixel to the right side of the peak P, and the
pixel value of the pixel to the left side of the peak P,

5   from the fine line region F thus detected, each with the
threshold value, detects a fine line pixel region F having
the peak P wherein the pixel value of the peak P exceeds the
threshold value, and wherein the pixel value of the pixel to
the right side of the peak P is the threshold value or lower,

10 and wherein the pixel value of the pixel to the left side of
the peak P is the threshold value or lower, and takes the
detected fine line region F as a candidate for the region
made up of pixels containing the component of the fine line
image.

15   In other words, determination is made that a fine line
region F having the peak P, wherein the pixel value of the
peak P is the threshold value or lower, or wherein the pixel
value of the pixel to the right side of the peak P exceeds
the threshold value, or wherein the pixel value of the pixel

20 to the left side of the peak P exceeds the threshold value,
does not contain the component of the fine line image, and
is eliminated from candidates for the region made up of
pixels including the component of the fine line image.

        That is, as shown in Fig. 37, the monotonous

25 increase/decrease detecting unit 203 compares the pixel

value of the peak P with the threshold value, and also

compares the pixel value of the pixel adjacent to the peak P

in the spatial direction X (the direction indicated by the

dotted line AA') with the threshold value, thereby detecting

5   the fine line region F to which the peak P belongs, wherein

the pixel value of the peak P exceeds the threshold value

and wherein the pixel values of the pixel adjacent thereto

in the spatial direction X are equal to or below the

threshold value.

10   Fig. 38 is a diagram illustrating the pixel values of

pixels arrayed in the spatial direction X indicated by the

dotted line AA' in Fig. 37. The fine line region F to which

the peak P belongs, wherein the pixel value of the peak P

exceeds the threshold value Th_s and wherein the pixel values

15   of the pixel adjacent thereto in the spatial direction X are

equal to or below the threshold value Th_s, contains the fine

line component.

Note that an arrangement may be made wherein the

monotonous increase/decrease detecting unit 203 compares the

20   difference between the pixel value of the peak P and the

pixel value of the background with the threshold value,

taking the pixel value of the background as a reference, and

also compares the difference between the pixel value of the

pixels adjacent to the peak P in the spatial direction X and

25   the pixel value of the background with the threshold value,

thereby detecting the fine line region F to which the peak P belongs, wherein the difference between the pixel value of the peak P and the pixel value of the background exceeds the threshold value, and wherein the difference between the

5   pixel value of the pixel adjacent in the spatial direction X and the pixel value of the background is equal to or below the threshold value.

The monotonous increase/decrease detecting unit 203 supplies to the continuousness detecting unit 204 monotonous

10   increase/decrease region information indicating a region made up of pixels of which the pixel value monotonously decrease with the peak P as a reference and the sign of the pixel value is the same as that of the peak P, wherein the peak P exceeds the threshold value and wherein the pixel

15   value of the pixel to the right side of the peak P is equal to or below the threshold value and the pixel value of the pixel to the left side of the peak P is equal to or below the threshold value.

In the event of detecting a region of pixels arrayed in

20   a single row in the vertical direction of the screen where the image of the fine line has been projected, pixels belonging to the region indicated by the monotonous increase/decrease region information are arrayed in the vertical direction and include pixels where the image of the

25   fine line has been projected. That is to say, the region

indicated by the monotonous increase/decrease region information includes a region formed of pixels arrayed in a single row in the vertical direction of the screen where the image of the fine line has been projected.

5   In this way, the peak detecting unit 202 and the monotonous increase/decrease detecting unit 203 detects a continuity region made up of pixels where the image of the fine line has been projected, employing the nature that, of the pixels where the image of the fine line has been

10   projected, change in the pixel values in the spatial direction Y approximates Gaussian distribution.

Of the region made up of pixels arrayed in the vertical direction, indicated by the monotonous increase/decrease region information supplied from the monotonous

15   increase/decrease detecting unit 203, the continuousness detecting unit 204 detects regions including pixels adjacent in the horizontal direction, i.e., regions having similar pixel value change and duplicated in the vertical direction, as continuous regions, and outputs the peak information and

20   data continuity information indicating the detected continuous regions. The data continuity information includes monotonous increase/decrease region information, information indicating the connection of regions, and so forth.

25   Arc shapes are aligned at constant intervals in an

adjacent manner with the pixels where the fine line has been
projected, so the detected continuous regions include the
pixels where the fine line has been projected.

The detected continuous regions include the pixels
where arc shapes are aligned at constant intervals in an
adjacent manner to which the fine line has been projected,
so the detected continuous regions are taken as a continuity
region, and the continuousness detecting unit 204 outputs
data continuity information indicating the detected
continuous regions.

That is to say, the continuousness detecting unit 204
uses the continuity wherein arc shapes are aligned at
constant intervals in an adjacent manner in the data 3
obtained by imaging the fine line, which has been generated
due to the continuity of the image of the fine line in the
actual world 1, the nature of the continuity being
continuing in the length direction, so as to further narrow
down the candidates of regions detected with the peak
detecting unit 202 and the monotonous increase/decrease
detecting unit 203.

Fig. 39 is a diagram describing the processing for
detecting the continuousness of monotonous increase/decrease
regions.

As shown in Fig. 39, in the event that a fine line
region F formed of pixels aligned in a single row in the

vertical direction of the screen includes pixels adjacent in the horizontal direction, the continuousness detecting unit 204 determines that there is continuousness between the two monotonous increase/decrease regions, and in the event that

5 pixels adjacent in the horizontal direction are not included, determines that there is no continuousness between the two fine line regions F. For example, a fine line region F_{-1} made up of pixels aligned in a single row in the vertical direction of the screen is determined to be continuous to a

10 fine line region F_0 made up of pixels aligned in a single row in the vertical direction of the screen in the event of containing a pixel adjacent to a pixel of the fine line region F_0 in the horizontal direction. The fine line region F_0 made up of pixels aligned in a single row in the vertical

15 direction of the screen is determined to be continuous to a fine line region F_1 made up of pixels aligned in a single row in the vertical direction of the screen in the event of containing a pixel adjacent to a pixel of the fine line region F_1 in the horizontal direction.

20 In this way, regions made up of pixels aligned in a single row in the vertical direction of the screen where the image of the fine line has been projected are detected by the peak detecting unit 202 through the continuousness detecting unit 204.

25 As described above, the peak detecting unit 202 through

the continuousness detecting unit 204 detect regions made up of pixels aligned in a single row in the vertical direction of the screen where the image of the fine line has been projected, and further detect regions made up of pixels

5   aligned in a single row in the horizontal direction of the screen where the image of the fine line has been projected.

Note that the order of processing is not particularly restricted, and may be executed in parallel, as a matter of course.

10   That is to say, the peak detecting unit 202, with regard to of pixels aligned in a single row in the horizontal direction of the screen, detects as a peak a pixel which has a pixel value greater in comparison with the pixel value of the pixel situated to the left side on the

15   screen and the pixel value of the pixel situated to the right side on the screen, and supplies peak information indicating the position of the detected peak to the monotonous increase/decrease detecting unit 203. The peak detecting unit 202 detects one or multiple peaks from one

20   image, for example, one frame image.

For example, the peak detecting unit 202 selects a pixel of interest from pixels in the one frame image which has not yet been taken as a pixel of interest, compares the pixel value of the pixel of interest with the pixel value of

25   the pixel to the left side of the pixel of interest,

compares the pixel value of the pixel of interest with the pixel value of the pixel to the right side of the pixel of interest, detects a pixel of interest having a pixel value greater than the pixel value of the pixel to the left side

5   of the pixel of interest and having a pixel value greater than the pixel value of the pixel to the right side of the pixel of interest, and takes the detected pixel of interest as a peak.   The peak detecting unit 202 supplies peak information indicating the detected peak to the monotonous

10   increase/decrease detecting unit 203.

There are cases wherein the peak detecting unit 202 does not detect a peak.

The monotonous increase/decrease detecting unit 203 detects candidates for a region made up of pixels aligned in

15   a single row in the horizontal direction as to the peak detected by the peak detecting unit 202 wherein the fine line image has been projected, and supplies the monotonous increase/decrease region information indicating the detected region to the continuousness detecting unit 204 along with

20   the peak information.

More specifically, the monotonous increase/decrease detecting unit 203 detects regions made up of pixels having pixel values monotonously decreasing with the pixel value of the peak as a reference, as candidates of regions made up of

25   pixels where the fine line image has been projected.

For example, the monotonous increase/decrease detecting
unit 203 obtains, with regard to each pixel in a single row
in the horizontal direction as to the peak, the pixel value
of each pixel, the difference as to the pixel value of the
5   pixel to the left side, and the difference as to the pixel
value of the pixel to the right side. The monotonous
increase/decrease detecting unit 203 then detects the region
where the pixel value monotonously decreases by detecting
the pixel where the sign of the difference changes.

10   Further, the monotonous increase/decrease detecting
unit 203 detects, from a region wherein pixel values
monotonously decrease, a region made up of pixels having
pixel values with the same sign as the pixel value as the
sign of the pixel value of the peak, with reference to the
15   sign of the pixel value of the peak, as a candidate for a
region made up of pixels where the fine line image has been
projected.

For example, the monotonous increase/decrease detecting
unit 203 compares the sign of the pixel value of each pixel
20   with the sign of the pixel value of the pixel to the left
side or with the sign of the pixel value of the pixel to the
right side, and detects the pixel where the sign of the
pixel value changes, thereby detecting a region made up of
pixels having pixel values with the same sign as the peak,
25   from the region where the pixel values monotonously decrease.

Thus, the monotonous increase/decrease detecting unit 203 detects a region made up of pixels aligned in the horizontal direction and having pixel values with the same sign as the peak wherein the pixel values monotonously

5   decrease as to the peak.

From a fine line region made up of such a monotonous increase/decrease region, the monotonous increase/decrease detecting unit 203 obtains a fine line region longer than a threshold value set beforehand, i.e., a fine line region

10 having a greater number of pixels than the threshold value.

Further, from the fine line region thus detected, the monotonous increase/decrease detecting unit 203 compares the pixel value of the peak, the pixel value of the pixel above the peak, and the pixel value of the pixel below the peak,

15 each with the threshold value, detects a fine line region to which belongs a peak wherein the pixel value of the peak exceeds the threshold value, the pixel value of the pixel above the peak is within the threshold, and the pixel value of the pixel below the peak is within the threshold, and

20 takes the detected fine line region as a candidate for a region made up of pixels containing the fine line image component.

Another way of saying this is that fine line regions to which belongs a peak wherein the pixel value of the peak is

25 within the threshold value, or the pixel value of the pixel

above the peak exceeds the threshold, or the pixel value of

the pixel below the peak exceeds the threshold, are

determined to not contain the fine line image component, and

are eliminated from candidates of the region made up of

5   pixels containing the fine line image component.

Note that the monotonous increase/decrease detecting

unit 203 may be arranged to take the background pixel value

as a reference, compare the difference between the pixel

value of the peak and the pixel value of the background with

10   the threshold value, and also to compare the difference

between the pixel value of the background and the pixel

values of the pixels adjacent to the peak in the vertical

direction with the threshold value, and take a detected fine

line region wherein the difference between the pixel value

15   of the peak and the pixel value of the background exceeds

the threshold value, and the difference between the pixel

value of the background and the pixel value of the pixels

adjacent in the vertical direction is within the threshold,

as a candidate for a region made up of pixels containing the

20   fine line image component.

The monotonous increase/decrease detecting unit 203

supplies to the continuousness detecting unit 204 monotonous

increase/decrease region information indicating a region

made up of pixels having a pixel value sign which is the

25   same as the peak and monotonously decreasing pixel values as

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to the peak as a reference, wherein the peak exceeds the
threshold value, and the pixel value of the pixel to the
right side of the peak is within the threshold, and the
pixel value of the pixel to the left side of the peak is
5   within the threshold.

In the event of detecting a region made up of pixels
aligned in a single row in the horizontal direction of the
screen wherein the image of the fine line has been projected,
pixels belonging to the region indicated by the monotonous
10   increase/decrease region information include pixels aligned
in the horizontal direction wherein the image of the fine
line has been projected. That is to say, the region
indicated by the monotonous increase/decrease region
information includes a region made up of pixels aligned in a
15   single row in the horizontal direction of the screen wherein
the image of the fine line has been projected.

Of the regions made up of pixels aligned in the
horizontal direction indicated in the monotonous
increase/decrease region information supplied from the
20   monotonous increase/decrease detecting unit 203, the
continuousness detecting unit 204 detects regions including
pixels adjacent in the vertical direction, i.e., regions
having similar pixel value change and which are repeated in
the horizontal direction, as continuous regions, and outputs
25   data continuity information indicating the peak information

and the detected continuous regions. The data continuity

information includes information indicating the connection

of the regions.

At the pixels where the fine line has been projected,

5   arc shapes are arrayed at constant intervals in an adjacent

manner, so the detected continuous regions include pixels

where the fine line has been projected.

The detected continuous regions include pixels where

arc shapes are arrayed at constant intervals in an adjacent

10   manner wherein the fine line has been projected, so the

detected continuous regions are taken as a continuity region,

and the continuousness detecting unit 204 outputs data

continuity information indicating the detected continuous

regions.

15   That is to say, the continuousness detecting unit 204

uses the continuity which is that the arc shapes are arrayed

at constant intervals in an adjacent manner in the data 3

obtained by imaging the fine line, generated from the

continuity of the image of the fine line in the actual world

20   1 which is continuation in the length direction, so as to

further narrow down the candidates of regions detected by

the peak detecting unit 202 and the monotonous

increase/decrease detecting unit 203.

Thus, the data continuity detecting unit 101 is capable

25   of detecting continuity contained in the data 3 which is the

input image. That is to say, the data continuity detecting

unit 101 can detect continuity of data included in the data

3 which has been generated by the actual world 1 image which

is a fine line having been projected on the data 3. The

5   data continuity detecting unit 101 detects, from the data 3,

regions made up of pixels where the actual world 1 image

which is a fine line has been projected.

Fig. 40 is a diagram illustrating an example of other

processing for detecting regions having continuity, where a

10   fine line image has been projected, with the data continuity

detecting unit 101.

As shown in Fig. 40, the data continuity detecting unit

101 calculates the absolute value of difference of pixel

values for each pixel and adjacent pixels. The calculated

15   absolute values of difference are placed corresponding to

the pixels. For example, in a situation such as shown in

Fig. 40 wherein there are pixels aligned which have

respective pixel values of P0, P1, and P2, the data

continuity detecting unit 101 calculates the difference d0 =

20   P0 - P1 and the difference d1 = P1 - P2. Further, the data

continuity detecting unit 101 calculates the absolute values

of the difference d0 and the difference d1.

In the event that the non-continuity component

contained in the pixel values P0, P1, and P2 are identical,

25   only values corresponding to the component of the fine line

are set to the difference d0 and the difference d1.

Accordingly, of the absolute values of the differences placed corresponding to the pixels, in the event that adjacent difference values are identical, the data

5 continuity detecting unit 101 determines that the pixel corresponding to the absolute values of the two differences (the pixel between the two absolute values of difference) contains the component of the fine line. However, the data continuity detecting unit 101 does not need to detect the

10 fine line in the event that the absolute value of difference is small. For example, in the event that the absolute value of difference is equal to or greater than a threshold value, the data continuity detecting unit 101 determines that the pixel contains a fine line component.

15 The data continuity detecting unit 101 can also detect fine lines with a simple method such as this.

Fig. 41 is a flowchart for describing continuity detection processing.

In step S201, the non-continuity component extracting

20 unit 201 extracts non-continuity component, which is portions other than the portion where the fine line has been projected, from the input image. The non-continuity component extracting unit 201 supplies non-continuity component information indicating the extracted non-

25 continuity component, along with the input image, to the

peak detecting unit 202 and the monotonous increase/decrease detecting unit 203. Details of the processing for extracting the non-continuity component will be described later.

5   In step S202, the peak detecting unit 202 eliminates the non-continuity component from the input image, based on the non-continuity component information supplied from the non-continuity component extracting unit 201, so as to leave only pixels including the continuity component in the input

10   image. Further, in step S202, the peak detecting unit 202 detects peaks.

That is to say, in the event of executing processing with the vertical direction of the screen as a reference, of the pixels containing the continuity component, the peak

15   detecting unit 202 compares the pixel value of each pixel with the pixel values of the pixels above and below, and detects pixels having a greater pixel value than the pixel value of the pixel above and the pixel value of the pixel below, thereby detecting a peak. Also, in step S202, in the

20   event of executing processing with the horizontal direction of the screen as a reference, of the pixels containing the continuity component, the peak detecting unit 202 compares the pixel value of each pixel with the pixel values of the pixels to the right side and left side, and detects pixels

25   having a greater pixel value than the pixel value of the

pixel to the right side and the pixel value of the pixel to the left side, thereby detecting a peak.

The peak detecting unit 202 supplies the peak information indicating the detected peaks to the monotonous

5   increase/decrease detecting unit 203.

In step S203, the monotonous increase/decrease detecting unit 203 eliminates the non-continuity component from the input image, based on the non-continuity component information supplied from the non-continuity component

10   extracting unit 201, so as to leave only pixels including the continuity component in the input image. Further, in step S203, the monotonous increase/decrease detecting unit 203 detects the region made up of pixels having data continuity, by detecting monotonous increase/decrease as to

15   the peak, based on peak information indicating the position of the peak, supplied from the peak detecting unit 202.

In the event of executing processing with the vertical direction of the screen as a reference, the monotonous increase/decrease detecting unit 203 detects monotonous

20   increase/decrease made up of one row of pixels aligned vertically where a single fine line image has been projected, based on the pixel value of the peak and the pixel values of the one row of pixels aligned vertically as to the peak, thereby detecting a region made up of pixels having data

25   continuity. That is to say, in step S203, in the event of

executing processing with the vertical direction of the
screen as a reference, the monotonous increase/decrease
detecting unit 203 obtains, with regard to a peak and a row
of pixels aligned vertically as to the peak, the difference

5   between the pixel value of each pixel and the pixel value of
a pixel above or below, thereby detecting a pixel where the
sign of the difference changes. Also, with regard to a peak
and a row of pixels aligned vertically as to the peak, the
monotonous increase/decrease detecting unit 203 compares the

10   sign of the pixel value of each pixel with the sign of the
pixel value of a pixel above or below, thereby detecting a
pixel where the sign of the pixel value changes. Further,
the monotonous increase/decrease detecting unit 203 compares
pixel value of the peak and the pixel values of the pixels

15   to the right side and to the left side of the peak with a
threshold value, and detects a region made up of pixels
wherein the pixel value of the peak exceeds the threshold
value, and wherein the pixel values of the pixels to the
right side and to the left side of the peak are within the

20   threshold.

The monotonous increase/decrease detecting unit 203
takes a region detected in this way as a monotonous
increase/decrease region, and supplies monotonous
increase/decrease region information indicating the

25   monotonous increase/decrease region to the continuousness

detecting unit 204.

In the event of executing processing with the horizontal direction of the screen as a reference, the monotonous increase/decrease detecting unit 203 detects

5 monotonous increase/decrease made up of one row of pixels aligned horizontally where a single fine line image has been projected, based on the pixel value of the peak and the pixel values of the one row of pixels aligned horizontally as to the peak, thereby detecting a region made up of pixels

10 having data continuity. That is to say, in step S203, in the event of executing processing with the horizontal direction of the screen as a reference, the monotonous increase/decrease detecting unit 203 obtains, with regard to a peak and a row of pixels aligned horizontally as to the

15 peak, the difference between the pixel value of each pixel and the pixel value of a pixel to the right side or to the left side, thereby detecting a pixel where the sign of the difference changes. Also, with regard to a peak and a row of pixels aligned horizontally as to the peak, the

20 monotonous increase/decrease detecting unit 203 compares the sign of the pixel value of each pixel with the sign of the pixel value of a pixel to the right side or to the left side, thereby detecting a pixel where the sign of the pixel value changes. Further, the monotonous increase/decrease

25 detecting unit 203 compares pixel value of the peak and the

pixel values of the pixels to the upper side and to the
lower side of the peak with a threshold value, and detects a
region made up of pixels wherein the pixel value of the peak
exceeds the threshold value, and wherein the pixel values of
5   the pixels to the upper side and to the lower side of the
peak are within the threshold.

The monotonous increase/decrease detecting unit 203
takes a region detected in this way as a monotonous
increase/decrease region, and supplies monotonous
10   increase/decrease region information indicating the
monotonous increase/decrease region to the continuousness
detecting unit 204.

In step S204, the monotonous increase/decrease
detecting unit 203 determines whether or not processing of
15   all pixels has ended. For example, the non-continuity
component extracting unit 201 detects peaks for all pixels
of a single screen (for example, frame, field, or the like)
of the input image, and whether or not a monotonous
increase/decrease region has been detected is determined.

20   In the event that determination is made in step S204
that processing of all pixels has not ended, i.e., that
there are still pixels which have not been subjected to the
processing of peak detection and detection of monotonous
increase/decrease region, the flow returns to step S202, a
25   pixel which has not yet been subjected to the processing of

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peak detection and detection of monotonous increase/decrease region is selected as an object of the processing, and the processing of peak detection and detection of monotonous increase/decrease region are repeated.

In the event that determination is made in step S204 that processing of all pixels has ended, i.e., that peaks and monotonous increase/decrease regions have been detected with regard to all pixels, the flow proceeds to step S205, where the continuousness detecting unit 204 detects the continuousness of detected regions, based on the monotonous increase/decrease region information. For example, in the event that monotonous increase/decrease regions made up of one row of pixels aligned in the vertical direction of the screen, indicated by monotonous increase/decrease region information, include pixels adjacent in the horizontal direction, the continuousness detecting unit 204 determines that there is continuousness between the two monotonous increase/decrease regions, and in the event of not including pixels adjacent in the horizontal direction, determines that there is no continuousness between the two monotonous increase/decrease regions. For example, in the event that monotonous increase/decrease regions made up of one row of pixels aligned in the horizontal direction of the screen, indicated by monotonous increase/decrease region information, include pixels adjacent in the vertical direction, the

continuousness detecting unit 204 determines that there is

continuousness between the two monotonous increase/decrease

regions, and in the event of not including pixels adjacent

in the vertical direction, determines that there is no

5 continuousness between the two monotonous increase/decrease

regions.

The continuousness detecting unit 204 takes the

detected continuous regions as continuity regions having

data continuity, and outputs data continuity information

10 indicating the peak position and continuity region. The

data continuity information contains information indicating

the connection of regions. The data continuity information

output from the continuousness detecting unit 204 indicates

the fine line region, which is the continuity region, made

15 up of pixels where the actual world 1 fine line image has

been projected.

In step S206, a continuity direction detecting unit 205

determines whether or not processing of all pixels has ended.

That is to say, the continuity direction detecting unit 205

20 determines whether or not region continuation has been

detected with regard to all pixels of a certain frame of the

input image.

In the event that determination is made in step S206

that processing of all pixels has not yet ended, i.e., that

25 there are still pixels which have not yet been taken as the

object of detection of region continuation, the flow returns
to step S205, a pixel which has not yet been subjected to
the processing of detection of region continuity is selected
as the pixel for processing, and the processing for
5 detection of region continuity is repeated.

In the event that determination is made in step S206
that processing of all pixels has ended, i.e., that all
pixels have been taken as the object of detection of region
continuity, the processing ends.

10   Thus, the continuity contained in the data 3 which is
the input image is detected. That is to say, continuity of
data included in the data 3 which has been generated by the
actual world 1 image which is a fine line having been
projected on the data 3 is detected, and a region having
15 data continuity, which is made up of pixels on which the
actual world 1 image which is a fine line has been projected,
is detected from the data 3.

Now, the data continuity detecting unit 101 of which
the configuration is shown in Fig. 30 can detect time-
20 directional data continuity, based on the region having data
continuity detected from the frame of the data 3.

For example, as shown in Fig. 42, the continuousness
detecting unit 204 detects time-directional data continuity
by connecting the edges of the region having detected data
25 continuity in frame #n, the region having detected data

continuity in frame #n-1, and the region having detected
data continuity in frame #n+1.

The frame #n-1 is a frame preceding the frame #n time-
wise, and the frame #n+1 is a frame following the frame #n
5   time-wise. That is to say, the frame #n-1, the frame #n,
and the frame #n+1, are displayed on the order of the frame
#n-1, the frame #n, and the frame #n+1.

More specifically, in Fig. 42, G denotes a movement
vector obtained by connecting the one edge of the region
10   having detected data continuity in frame #n, the region
having detected data continuity in frame #n-1, and the
region having detected data continuity in frame #n+1, and G'
denotes a movement vector obtained by connecting the other
edges of the regions having detected data continuity. The
15   movement vector G and the movement vector G' are an example
of data continuity in the time direction.

Further, the data continuity detecting unit 101 of
which the configuration is shown in Fig. 30 can output
information indicating the length of the region having data
20   continuity as data continuity information.

Fig. 43 is a block diagram illustrating the
configuration of the non-continuity component extracting
unit 201 which performs planar approximation of the non-
continuity component which is the portion of the image data
25   which does not have data continuity, and extracts the non-

continuity component.

The non-continuity component extracting unit 201 of which the configuration is shown in Fig. 43 extracts blocks, which are made up of a predetermined number of pixels, from

5   the input image, performs planar approximation of the blocks, so that the error between the block and a planar value is below a predetermined threshold value, thereby extracting the non-continuity component.

The input image is supplied to a block extracting unit

10 221, and is also output without change.

The block extracting unit 221 extracts blocks, which are made up of a predetermined number of pixels, from the input image. For example, the block extracting unit 221 extracts a block made up of 7 × 7 pixels, and supplies this

15 to a planar approximation unit 222. For example, the block extracting unit 221 moves the pixel serving as the center of the block to be extracted in raster scan order, thereby sequentially extracting blocks from the input image.

The planar approximation unit 222 approximates the

20 pixel values of a pixel contained in the block on a predetermined plane. For example, the planar approximation unit 222 approximates the pixel value of a pixel contained in the block on a plane expressed by Expression (32).

$$z = ax + by + c$$

25   ...(32)

In Expression (32), x represents the position of the

pixel in one direction on the screen (the spatial direction

X), and y represents the position of the pixel in the other

direction on the screen (the spatial direction Y). z

5 represents the application value represented by the plane.

a represents the gradient of the spatial direction X of the

plane, and b represents the gradient of the spatial

direction Y of the plane. In Expression (32), c represents

the offset of the plane (intercept).

10   For example, the planar approximation unit 222 obtains

the gradient a, gradient b, and offset c, by regression

processing, thereby approximating the pixel values of the

pixels contained in the block on a plane expressed by

Expression (32). The planar approximation unit 222 obtains

15 the gradient a, gradient b, and offset c, by regression

processing including rejection, thereby approximating the

pixel values of the pixels contained in the block on a plane

expressed by Expression (32).

For example, the planar approximation unit 222 obtains

20 the plane expressed by Expression (32) wherein the error is

least as to the pixel values of the pixels of the block

using the least-square method, thereby approximating the

pixel values of the pixels contained in the block on the

plane.

25   Note that while the planar approximation unit 222 has

been described approximating the block on the plane

expressed by Expression (32), this is not restricted to the

plane expressed by Expression (32), rather, the block may be

approximated on a plane represented with a function with a

5   higher degree of freedom, for example, an n-order (wherein n

is an arbitrary integer) polynomial.

A repetition determining unit 223 calculates the error

between the approximation value represented by the plane

upon which the pixel values of the block have been

10   approximated, and the corresponding pixel values of the

pixels of the block. Expression (33) is an expression which

shows the error ei which is the difference between the

approximation value represented by the plane upon which the

pixel values of the block have been approximated, and the

15   corresponding pixel values zi of the pixels of the block.

$$e_i = z_i - \hat{z} = z_i - (\hat{a}x_i + \hat{b}y_i + \hat{c})$$

...(33)

In Expression (33), z-hat (A symbol with ^ over z will

be described as z-hat. The same description will be used in

20   the present specification hereafter.) represents an

approximation value expressed by the plane on which the

pixel values of the block are approximated, a-hat represents

the gradient of the spatial direction X of the plane on

which the pixel values of the block are approximated, b-hat

25   represents the gradient of the spatial direction Y of the

plane on which the pixel values of the block are approximated, and c-hat represents the offset (intercept) of the plane on which the pixel values of the block are approximated.

5   The repetition determining unit 223 rejects the pixel regarding which the error ei between the approximation value and the corresponding pixel values of pixels of the block is greatest, shown in Expression (33). Thus, pixels where the fine line has been projected, i.e., pixels having continuity,

10   are rejected. The repetition determining unit 223 supplies rejection information indicating the rejected pixels to the planar approximation unit 222.

      Further, the repetition determining unit 223 calculates a standard error, and in the event that the standard error

15   is equal to or greater than threshold value which has been set beforehand for determining ending of approximation, and half or more of the pixels of the pixels of a block have not been rejected, the repetition determining unit 223 causes the planar approximation unit 222 to repeat the processing

20   of planar approximation on the pixels contained in the block, from which the rejected pixels have been eliminated.

      Pixels having continuity are rejected, so approximating the pixels from which the rejected pixels have been eliminated on a plane means that the plane approximates the

25   non-continuity component.

At the point that the standard error below the threshold value for determining ending of approximation, or half or more of the pixels of the pixels of a block have been rejected, the repetition determining unit 223 ends

5 planar approximation.

With a block made up of 5 × 5 pixels, the standard error e_s can be calculated with, for example, Expression (34).

$$e_s = \sum (z_i - \hat{z}) / (n-3)$$
$$= \sum \{(z_i - (\hat{a}x_i + \hat{b}y_i + \hat{c}))\} / (n-3)$$

10   ...(34)

Here, n is the number of pixels.

Note that the repetition determining unit 223 is not restricted to standard error, and may be arranged to calculate the sum of the square of errors for all of the

15 pixels contained in the block, and perform the following processing.

Now, at the time of planar approximation of blocks shifted one pixel in the raster scan direction, a pixel having continuity, indicated by the black circle in the

20 diagram, i.e., a pixel containing the fine line component, will be rejected multiple times, as shown in Fig. 44.

Upon completing planar approximation, the repetition determining unit 223 outputs information expressing the

plane for approximating the pixel values of the block (the gradient and intercept of the plane of Expression 32)) as non-continuity information.

Note that an arrangement may be made wherein the
5   repetition determining unit 223 compares the number of times of rejection per pixel with a preset threshold value, and takes a pixel which has been rejected a number of times equal to or greater than the threshold value as a pixel containing the continuity component, and output the
10   information indicating the pixel including the continuity component as continuity component information. In this case, the peak detecting unit 202 through the continuity direction detecting unit 205 execute their respective processing on pixels containing continuity component, indicated by the
15   continuity component information.

The number of times of rejection, the gradient of the spatial direction X of the plane for approximating the pixel values of the pixel of the block, the gradient of the spatial direction Y of the plane for approximating the pixel
20   values of the pixel of the block, approximation values expressed by the plane approximating the pixel values of the pixels of the block, and the error e_i, can be used as features of the input image.

Fig. 45 is a flowchart for describing the processing of
25   extracting the non-continuity component with the non-

continuity component extracting unit 201 of which the configuration is shown in Fig. 43, corresponding to step S201.

In step S221, the block extracting unit 221 extracts a
5   block made up of a predetermined number of pixels from the input image, and supplies the extracted block to the planar approximation unit 222. For example, the block extracting unit 221 selects one pixel of the pixels of the input pixel which have not been selected yet, and extracts a block made
10 up of 7 × 7 pixels centered on the selected pixel. For example, the block extracting unit 221 can select pixels in raster scan order.

In step S222, the planar approximation unit 222 approximates the extracted block on a plane. The planar
15 approximation unit 222 approximates the pixel values of the pixels of the extracted block on a plane by regression processing, for example. For example, the planar approximation unit 222 approximates the pixel values of the pixels of the extracted block excluding the rejected pixels
20 on a plane, by regression processing. In step S223, the repetition determining unit 223 executes repetition determination. For example, repetition determination is performed by calculating the standard error from the pixel values of the pixels of the block and the planar
25 approximation values, and counting the number of rejected

pixels.

In step S224, the repetition determining unit 223 determines whether or not the standard error is equal to or above a threshold value, and in the event that determination

5   is made that the standard error is equal to or above the threshold value, the flow proceeds to step S225.

Note that an arrangement may be made wherein the repetition determining unit 223 determines in step S224 whether or not half or more of the pixels of the block have

10   been rejected, and whether or not the standard error is equal to or above the threshold value, and in the event that determination is made that half or more of the pixels of the block have not been rejected, and the standard error is equal to or above the threshold value, the flow proceeds to

15   step S225.

In step S225, the repetition determining unit 223 calculates the error between the pixel value of each pixel of the block and the approximated planar approximation value, rejects the pixel with the greatest error, and notifies the

20   planar approximation unit 222. The procedure returns to step S222, and the planar approximation processing and repetition determination processing is repeated with regard to the pixels of the block excluding the rejected pixel.

In step S225, in the event that a block which is

25   shifted one pixel in the raster scan direction is extracted

in the processing in step S221, the pixel including the fine

line component (indicated by the black circle in the

drawing) is rejected multiple times, as shown in Fig. 44.

In the event that determination is made in step S224

5   that the standard error is not equal to or greater than the

threshold value, the block has been approximated on the

plane, so the flow proceeds to step S226.

Note that an arrangement may be made wherein the

repetition determining unit 223 determines in step S224

10   whether or not half or more of the pixels of the block have

been rejected, and whether or not the standard error is

equal to or above the threshold value, and in the event that

determination is made that half or more of the pixels of the

block have been rejected, or the standard error is not equal

15   to or above the threshold value, the flow proceeds to step

S225.

In step S226, the repetition determining unit 223

outputs the gradient and intercept of the plane for

approximating the pixel values of the pixels of the block as

20   non-continuity component information.

In step S227, the block extracting unit 221 determines

whether or not processing of all pixels of one screen of the

input image has ended, and in the event that determination

is made that there are still pixels which have not yet been

25   taken as the object of processing, the flow returns to step

S221, a block is extracted from pixels not yet been
subjected to the processing, and the above processing is
repeated.

5 In the event that determination is made in step S227
that processing has ended for all pixels of one screen of
the input image, the processing ends.

Thus, the non-continuity component extracting unit 201
of which the configuration is shown in Fig. 43 can extract
the non-continuity component from the input image. The non-
10 continuity component extracting unit 201 extracts the non-
continuity component from the input image, so the peak
detecting unit 202 and monotonous increase/decrease
detecting unit 203 can obtain the difference between the
input image and the non-continuity component extracted by
15 the non-continuity component extracting unit 201, so as to
execute the processing regarding the difference containing
the continuity component.

Note that the standard error in the event that
rejection is performed, the standard error in the event that
20 rejection is not performed, the number of times of rejection
of a pixel, the gradient of the spatial direction X of the
plane (a-hat in Expression (32)), the gradient of the
spatial direction Y of the plane (b-hat in Expression (32)),
the level of planar transposing (c-hat in Expression (32)),
25 and the difference between the pixel values of the input

image and the approximation values represented by the plane, calculated in planar approximation processing, can be used as features.

Fig. 46 is a flowchart for describing processing for
5   extracting the continuity component with the non-continuity component extracting unit 201 of which the configuration is shown in Fig. 43, instead of the processing for extracting the non-continuity component corresponding to step S201. The processing of step S241 through step S245 is the same as
10   the processing of step S221 through step S225, so description thereof will be omitted.

In step S246, the repetition determining unit 223 outputs the difference between the approximation value represented by the plane and the pixel values of the input
15   image, as the continuity component of the input image. That is to say, the repetition determining unit 223 outputs the difference between the planar approximation values and the true pixel values.

Note that the repetition determining unit 223 may be
20   arranged to output the difference between the approximation value represented by the plane and the pixel values of the input image, regarding pixel values of pixels of which the difference is equal to or greater than a predetermined threshold value, as the continuity component of the input
25   image.

The processing of step S247 is the same as the processing of step S227, and accordingly description thereof will be omitted.

The plane approximates the non-continuity component, so 5 the non-continuity component extracting unit 201 can remove the non-continuity component from the input image by subtracting the approximation value represented by the plane for approximating pixel values, from the pixel values of each pixel in the input image. In this case, the peak 10 detecting unit 202 through the continuousness detecting unit 204 can be made to process only the continuity component of the input image, i.e., the values where the fine line image has been projected, so the processing with the peak detecting unit 202 through the continuousness detecting unit 15 204 becomes easier.

Fig. 47 is a flowchart for describing other processing for extracting the continuity component with the non-continuity component extracting unit 201 of which the configuration is shown in Fig. 43, instead of the processing 20 for extracting the non-continuity component corresponding to step S201. The processing of step S261 through step S265 is the same as the processing of step S221 through step S225, so description thereof will be omitted.

In step S266, the repetition determining unit 223 25 stores the number of times of rejection for each pixel, the

flow returns to step S262, and the processing is repeated.

In step S264, in the event that determination is made that the standard error is not equal to or greater than the threshold value, the block has been approximated on the

5   plane, so the flow proceeds to step S267, the repetition determining unit 223 determines whether or not processing of all pixels of one screen of the input image has ended, and in the event that determination is made that there are still pixels which have not yet been taken as the object of

10   processing, the flow returns to step S261, with regard to a pixel which has not yet been subjected to the processing, a block is extracted, and the above processing is repeated.

In the event that determination is made in step S267 that processing has ended for all pixels of one screen of

15   the input image, the flow proceeds to step S268, the repetition determining unit 223 selects a pixel which has not yet been selected, and determines whether or not the number of times of rejection of the selected pixel is equal to or greater than a threshold value. For example, the

20   repetition determining unit 223 determines in step S268 whether or not the number of times of rejection of the selected pixel is equal to or greater than a threshold value stored beforehand.

In the event that determination is made in step S268

25   that the number of times of rejection of the selected pixel

is equal to or greater than the threshold value, the selected pixel contains the continuity component, so the flow proceeds to step S269, where the repetition determining unit 223 outputs the pixel value of the selected pixel (the

5   pixel value in the input image) as the continuity component of the input image, and the flow proceeds to step S270.

In the event that determination is made in step S268 that the number of times of rejection of the selected pixel is not equal to or greater than the threshold value, the

10   selected pixel does not contain the continuity component, so the processing in step S269 is skipped, and the procedure proceeds to step S270. That is to say, the pixel value of a pixel regarding which determination has been made that the number of times of rejection is not equal to or greater than

15   the threshold value is not output.

Note that an arrangement may be made wherein the repetition determining unit 223 outputs a pixel value set to 0 for pixels regarding which determination has been made that the number of times of rejection is not equal to or

20   greater than the threshold value.

In step S270, the repetition determining unit 223 determines whether or not processing of all pixels of one screen of the input image has ended to determine whether or not the number of times of rejection is equal to or greater

25   than the threshold value, and in the event that

determination is made that processing has not ended for all

pixels, this means that there are still pixels which have

not yet been taken as the object of processing, so the flow

returns to step S268, a pixel which has not yet been

5   subjected to the processing is selected, and the above

processing is repeated.

In the event that determination is made in step S270

that processing has ended for all pixels of one screen of

the input image, the processing ends.

10   Thus, of the pixels of the input image, the non-

continuity component extracting unit 201 can output the

pixel values of pixels containing the continuity component,

as continuity component information. That is to say, of the

pixels of the input image, the non-continuity component

15   extracting unit 201 can output the pixel values of pixels

containing the component of the fine line image.

Fig. 48 is a flowchart for describing yet other

processing for extracting the continuity component with the

non-continuity component extracting unit 201 of which the

20   configuration is shown in Fig. 43, instead of the processing

for extracting the non-continuity component corresponding to

step S201. The processing of step S281 through step S288 is

the same as the processing of step S261 through step S268,

so description thereof will be omitted.

25   In step S289, the repetition determining unit 223

outputs the difference between the approximation value represented by the plane, and the pixel value of a selected pixel, as the continuity component of the input image. That is to say, the repetition determining unit 223 outputs an

5 image wherein the non-continuity component has been removed from the input image, as the continuity information.

The processing of step S290 is the same as the processing of step S270, and accordingly description thereof will be omitted.

10 Thus, the non-continuity component extracting unit 201 can output an image wherein the non-continuity component has been removed from the input image as the continuity information.

As described above, in a case wherein real world light

15 signals are projected, a non-continuous portion of pixel values of multiple pixels of first image data wherein a part of the continuity of the real world light signals has been lost is detected, data continuity is detected from the detected non-continuous portions, a model (function) is

20 generated for approximating the light signals by estimating the continuity of the real world light signals based on the detected data continuity, and second image data is generated based on the generated function, processing results which are more accurate and have higher precision as to the event

25 in the real world can be obtained.

Fig. 49 is a block diagram illustrating another configuration of the data continuity detecting unit 101.

With the data continuity detecting unit 101 of which the configuration is shown in Fig. 49, change in the pixel

5　value of the pixel of interest which is a pixel of interest in the spatial direction of the input image, i.e. activity in the spatial direction of the input image, is detected, multiple sets of pixels made up of a predetermined number of pixels in one row in the vertical direction or one row in

10　the horizontal direction are extracted for each angle based on the pixel of interest and a reference axis according to the detected activity, the correlation of the extracted pixel sets is detected, and the angle of data continuity based on the reference axis in the input image is detected

15　based on the correlation.

The angle of data continuity means an angle assumed by the reference axis, and the direction of a predetermined dimension where continuity repeatedly appear in the data 3. Continuity repeatedly appearing means a case wherein, for

20　example, the change in value as to the change in position in the data 3, i.e., the cross-sectional shape, is the same, and so forth.

The reference axis may be, for example, an axis indicating the spatial direction X (the horizontal direction

25　of the screen), an axis indicating the spatial direction Y

(the vertical direction of the screen), and so forth.

The input image is supplied to an activity detecting unit 401 and data selecting unit 402.

The activity detecting unit 401 detects change in the pixel values as to the spatial direction of the input image, i.e., activity in the spatial direction, and supplies the activity information which indicates the detected results to the data selecting unit 402 and a continuity direction derivation unit 404.

For example, the activity detecting unit 401 detects the change of a pixel value as to the horizontal direction of the screen, and the change of a pixel value as to the vertical direction of the screen, and compares the detected change of the pixel value in the horizontal direction and the change of the pixel value in the vertical direction, thereby detecting whether the change of the pixel value in the horizontal direction is greater as compared with the change of the pixel value in the vertical direction, or whether the change of the pixel value in the vertical direction is greater as compared with the change of the pixel value in the horizontal direction.

The activity detecting unit 401 supplies to the data selecting unit 402 and the continuity direction derivation unit 404 activity information, which is the detection results, indicating that the change of the pixel value in

the horizontal direction is greater as compared with the change of the pixel value in the vertical direction, or indicating that the change of the pixel value in the vertical direction is greater as compared with the change of

5   the pixel value in the horizontal direction.

In the event that the change of the pixel value in the horizontal direction is greater as compared with the change of the pixel value in the vertical direction, arc shapes (half-disc shapes) or pawl shapes are formed on one row of

10   pixels in the vertical direction, as indicated by Fig. 50 for example, and the arc shapes or pawl shapes are formed repetitively more in the vertical direction. That is to say, in the event that the change of the pixel value in the horizontal direction is greater as compared with the change

15   of the pixel value in the vertical direction, with the reference axis as the axis representing the spatial direction X, the angle of the data continuity based on the reference axis in the input image is a value of any from 45 degrees to 90 degrees.

20   In the event that the change of the pixel value in the vertical direction is greater as compared with the change of the pixel value in the horizontal direction, arc shapes or pawl shapes are formed on one row of pixels in the vertical direction, for example, and the arc shapes or pawl shapes

25   are formed repetitively more in the horizontal direction.

That is to say, in the event that the change of the pixel value in the vertical direction is greater as compared with the change of the pixel value in the horizontal direction, with the reference axis as the axis representing the spatial

5   direction X, the angle of the data continuity based on the reference axis in the input image is a value of any from 0 degrees to 45 degrees.

For example, the activity detecting unit 401 extracts from the input image a block made up of the 9 pixels, 3 × 3

10 centered on the pixel of interest, as shown in Fig. 51. The activity detecting unit 401 calculates the sum of differences of the pixels values regarding the pixels vertically adjacent, and the sum of differences of the pixels values regarding the pixels horizontally adjacent.

15 The sum of differences h_{diff} of the pixels values regarding the pixels horizontally adjacent can be obtained with Expression (35).

$$h_{diff} = \sum (P_{i+1, j} - P_{i, j})$$

$$\ldots (35)$$

20   In the same way, the sum of differences v_{diff} of the pixels values regarding the pixels vertically adjacent can be obtained with Expression (36).

$$v_{diff} = \sum (P_{i, j+1} - P_{i, j})$$

... (36)

In Expression (35) and Expression (36), P represents
the pixel value, i represents the position of the pixel in
the horizontal direction, and j represents the position of
5   the pixel in the vertical direction.

An arrangement may be made wherein the activity
detecting unit 401 compares the calculated sum of
differences h_{diff} of the pixels values regarding the pixels
horizontally adjacent with the sum of differences v_{diff} of
10   the pixels values regarding the pixels vertically adjacent,
so as to determine the range of the angle of the data
continuity based on the reference axis in the input image.
That is to say, in this case, the activity detecting unit
401 determines whether a shape indicated by change in the
15   pixel value as to the position in the spatial direction is
formed repeatedly in the horizontal direction, or formed
repeatedly in the vertical direction.

For example, change in pixel values in the horizontal
direction with regard to an arc formed on pixels in one
20   horizontal row is greater than the change of pixel values in
the vertical direction, change in pixel values in the
vertical direction with regard to an arc formed on pixels in
one horizontal row is greater than the change of pixel
values in the horizontal direction, and it can be said that
25   the direction of data continuity, i.e., the change in the

direction of the predetermined dimension of a constant

feature which the input image that is the data 3 has is

smaller in comparison with the change in the orthogonal

direction too the data continuity. In other words, the

5   difference of the direction orthogonal to the direction of

data continuity (hereafter also referred to as non-

continuity direction) is greater as compared to the

difference in the direction of data continuity.

For example, as shown in Fig. 52, the activity

10   detecting unit 401 compares the calculated sum of

differences h_{diff} of the pixels values regarding the pixels

horizontally adjacent with the sum of differences v_{diff} of

the pixels values regarding the pixels vertically adjacent,

and in the event that the sum of differences h_{diff} of the

15   pixels values regarding the pixels horizontally adjacent is

greater, determines that the angle of the data continuity

based on the reference axis is a value of any from 45

degrees to 135 degrees, and in the event that the sum of

differences v_{diff} of the pixels values regarding the pixels

20   vertically adjacent is greater, determines that the angle of

the data continuity based on the reference axis is a value

of any from 0 degrees to 45 degrees, or a value of any from

135 degrees to 180 degrees.

For example, the activity detecting unit 401 supplies

25   activity information indicating the determination results to

the data selecting unit 402 and the continuity direction derivation unit 404.

Note that the activity detecting unit 401 can detect activity by extracting blocks of arbitrary sizes, such as a

5   block made up of 25 pixels of 5 × 5, a block made up of 49 pixels of 7 × 7, and so forth.

The data selecting unit 402 sequentially selects pixels of interest from the pixels of the input image, and extracts multiple sets of pixels made up of a predetermined number of

10   pixels in one row in the vertical direction or one row in the horizontal direction for each angle based on the pixel of interest and the reference axis, based on the activity information supplied from the activity detecting unit 401.

For example, in the event that the activity information

15   indicates that the change in pixel values in the horizontal direction is greater in comparison with the change in pixel values in the vertical direction, this means that the data continuity angle is a value of any from 45 degrees to 135 degrees, so the data selecting unit 402 extracts multiple

20   sets of pixels made up of a predetermined number of pixels in one row in the vertical direction, for each predetermined angle in the range of 45 degrees to 135 degrees, based on the pixel of interest and the reference axis.

In the event that the activity information indicates

25   that the change in pixel values in the vertical direction is

greater in comparison with the change in pixel values in the horizontal direction, this means that the data continuity angle is a value of any from 0 degrees to 45 degrees or from 135 degrees to 180 degrees, so the data selecting unit 402

5   extracts multiple sets of pixels made up of a predetermined number of pixels in one row in the horizontal direction, for each predetermined angle in the range of 0 degrees to 45 degrees or 135 degrees to 180 degrees, based on the pixel of interest and the reference axis.

10   Also, for example, in the event that the activity information indicates that the angle of data continuity is a value of any from 45 degrees to 135 degrees, the data selecting unit 402 extracts multiple sets of pixels made up of a predetermined number of pixels in one row in the

15   vertical direction, for each predetermined angle in the range of 45 degrees to 135 degrees, based on the pixel of interest and the reference axis.

In the event that the activity information indicates that the angle of data continuity is a value of any from 0

20   degrees to 45 degrees or from 135 degrees to 180 degrees, the data selecting unit 402 extracts multiple sets of pixels made up of a predetermined number of pixels in one row in the horizontal direction, for each predetermined angle in the range of 0 degrees to 45 degrees or 135 degrees to 180

25   degrees, based on the pixel of interest and the reference

axis.

The data selecting unit 402 supplies the multiple sets made up of the extracted pixels to an error estimating unit 403.

5   The error estimating unit 403 detects correlation of pixel sets for each angle with regard to the multiple sets of extracted pixels.

For example, with regard to the multiple sets of pixels made up of a predetermined number of pixels in one row in 10   the vertical direction corresponding to one angle, the error estimating unit 403 detects the correlation of the pixels values of the pixels at corresponding positions of the pixel sets. With regard to the multiple sets of pixels made up of a predetermined number of pixels in one row in the 15   horizontal direction corresponding to one angle, the error estimating unit 403 detects the correlation of the pixels values of the pixels at corresponding positions of the sets.

The error estimating unit 403 supplies correlation information indicating the detected correlation to the 20   continuity direction derivation unit 404. The error estimating unit 403 calculates the sum of the pixel values of pixels of a set including the pixel of interest supplied from the data selecting unit 402 as values indicating correlation, and the absolute value of difference of the 25   pixel values of the pixels at corresponding positions in

other sets, and supplies the sum of absolute value of
difference to the continuity direction derivation unit 404
as correlation information.

Based on the correlation information supplied from the
5   error estimating unit 403, the continuity direction
derivation unit 404 detects the data continuity angle based
on the reference axis in the input image, corresponding to
the lost continuity of the light signals of the actual world
1, and outputs data continuity information indicating an
10   angle. For example, based on the correlation information
supplied from the error estimating unit 403, the continuity
direction derivation unit 404 detects an angle corresponding
to the pixel set with the greatest correlation as the data
continuity angle, and outputs data continuity information
15   indicating the angle corresponding to the pixel set with the
greatest correlation that has been detected.

The following description will be made regarding
detection of data continuity angle in the range of 0 degrees
through 90 degrees (the so-called first quadrant).

20   Fig. 53 is a block diagram illustrating a more detailed
configuration of the data continuity detecting unit 101
shown in Fig. 49.

The data selecting unit 402 includes pixel selecting
unit 411-1 through pixel selecting unit 411-L. The error
25   estimating unit 403 includes estimated error calculating

unit 412-1 through estimated error calculating unit 412-L.

The continuity direction derivation unit 404 includes a

smallest error angle selecting unit 413.

First, description will be made regarding the

5   processing of the pixel selecting unit 411-1 through pixel

selecting unit 411-L in the event that the data continuity

angle indicated by the activity information is a value of

any from 45 degrees to 135 degrees.

The pixel selecting unit 411-1 through pixel selecting

10 unit 411-L set straight lines of mutually differing

predetermined angles which pass through the pixel of

interest, with the axis indicating the spatial direction X

as the reference axis. The pixel selecting unit 411-1

through pixel selecting unit 411-L select, of the pixels

15 belonging to a vertical row of pixels to which the pixel of

interest belongs, a predetermined number of pixels above the

pixel of interest, and predetermined number of pixels below

the pixel of interest, and the pixel of interest, as a set.

For example, as shown in Fig. 54, the pixel selecting

20 unit 411-1 through pixel selecting unit 411-L select 9

pixels centered on the pixel of interest, as a set of pixels,

from the pixels belonging to a vertical row of pixels to

which the pixel of interest belongs.

In Fig. 54, one grid-shaped square (one grid)

25 represents one pixel. In Fig. 54, the circle shown at the

center represents the pixel of interest.

The pixel selecting unit 411-1 through pixel selecting unit 411-L select, from pixels belonging to a vertical row of pixels to the left of the vertical row of pixels to which the pixel of interest belongs, a pixel at the position closest to the straight line set for each. In Fig. 54, the circle to the lower left of the pixel of interest represents an example of a selected pixel. The pixel selecting unit 411-1 through pixel selecting unit 411-L then select, from the pixels belonging to the vertical row of pixels to the left of the vertical row of pixels to which the pixel of interest belongs, a predetermined number of pixels above the selected pixel, a predetermined number of pixels below the selected pixel, and the selected pixel, as a set of pixels.

For example, as shown in Fig. 54, the pixel selecting unit 411-1 through pixel selecting unit 411-L select 9 pixels centered on the pixel at the position closest to the straight line, from the pixels belonging to the vertical row of pixels to the left of the vertical row of pixels to which the pixel of interest belongs, as a set of pixels.

The pixel selecting unit 411-1 through pixel selecting unit 411-L select, from pixels belonging to a vertical row of pixels second left from the vertical row of pixels to which the pixel of interest belongs, a pixel at the position closest to the straight line set for each. In Fig. 54, the

circle to the far left represents an example of the selected

pixel. The pixel selecting unit 411-1 through pixel

selecting unit 411-L then select, as a set of pixels, from

the pixels belonging to the vertical row of pixels second

5   left from the vertical row of pixels to which the pixel of

interest belongs, a predetermined number of pixels above the

selected pixel, a predetermined number of pixels below the

selected pixel, and the selected pixel.

For example, as shown in Fig. 54, the pixel selecting

10   unit 411-1 through pixel selecting unit 411-L select 9

pixels centered on the pixel at the position closest to the

straight line, from the pixels belonging to the vertical row

of pixels second left from the vertical row of pixels to

which the pixel of interest belongs, as a set of pixels.

15   The pixel selecting unit 411-1 through pixel selecting

unit 411-L select, from pixels belonging to a vertical row

of pixels to the right of the vertical row of pixels to

which the pixel of interest belongs, a pixel at the position

closest to the straight line set for each. In Fig. 54, the

20   circle to the upper right of the pixel of interest

represents an example of a selected pixel. The pixel

selecting unit 411-1 through pixel selecting unit 411-L then

select, from the pixels belonging to the vertical row of

pixels to the right of the vertical row of pixels to which

25   the pixel of interest belongs, a predetermined number of

pixels above the selected pixel, a predetermined number of
pixels below the selected pixel, and the selected pixel, as
a set of pixels.

For example, as shown in Fig. 54, the pixel selecting

5   unit 411-1 through pixel selecting unit 411-L select 9
pixels centered on the pixel at the position closest to the
straight line, from the pixels belonging to the vertical row
of pixels to the right of the vertical row of pixels to
which the pixel of interest belongs, as a set of pixels.

10   The pixel selecting unit 411-1 through pixel selecting
unit 411-L select, from pixels belonging to a vertical row
of pixels second right from the vertical row of pixels to
which the pixel of interest belongs, a pixel at the position
closest to the straight line set for each. In Fig. 54, the

15   circle to the far right represents an example of the
selected pixel. The pixel selecting unit 411-1 through
pixel selecting unit 411-L then select, from the pixels
belonging to the vertical row of pixels second right from
the vertical row of pixels to which the pixel of interest

20   belongs, a predetermined number of pixels above the selected
pixel, a predetermined number of pixels below the selected
pixel, and the selected pixel, as a set of pixels.

For example, as shown in Fig. 54, the pixel selecting
unit 411-1 through pixel selecting unit 411-L select 9

25   pixels centered on the pixel at the position closest to the

straight line, from the pixels belonging to the vertical row

of pixels second right from the vertical row of pixels to

which the pixel of interest belongs, as a set of pixels.

Thus, the pixel selecting unit 411-1 through pixel

5   selecting unit 411-L each select five sets of pixels.

The pixel selecting unit 411-1 through pixel selecting

unit 411-L select pixel sets for (lines set to) mutually

different angles. For example, the pixel selecting unit

411-1 selects sets of pixels regarding 45 degrees, the pixel

10   selecting unit 411-2 selects sets of pixels regarding 47.5

degrees, and the pixel selecting unit 411-3 selects sets of

pixels regarding 50 degrees. The pixel selecting unit 411-1

through pixel selecting unit 411-L select sets of pixels

regarding angles every 2.5 degrees, from 52.5 degrees

15   through 135 degrees.

Note that the number of pixel sets may be an optional

number, such as 3 or 7, for example, and does not restrict

the present invention. Also, the number of pixels selected

as one set may be an optional number, such as 5 or 13, for

20   example, and does not restrict the present invention.

Note that the pixel selecting unit 411-1 through pixel

selecting unit 411-L may be arranged to select pixel sets

from pixels within a predetermined range in the vertical

direction. For example, the pixel selecting unit 411-1

25   through pixel selecting unit 411-L can select pixel sets

from 121 pixels in the vertical direction (60 pixels upward from the pixel of interest, and 60 pixels downward). In this case, the data continuity detecting unit 101 can detect the angle of data continuity up to 88.09 degrees as to the

5 axis representing the spatial direction X.

The pixel selecting unit 411-1 supplies the selected set of pixels to the estimated error calculating unit 412-1, and the pixel selecting unit 411-2 supplies the selected set of pixels to the estimated error calculating unit 412-2. In

10 the same way, each pixel selecting unit 411-3 through pixel selecting unit 411-L supplies the selected set of pixels to each estimated error calculating unit 412-3 through estimated error calculating unit 412-L.

The estimated error calculating unit 412-1 through

15 estimated error calculating unit 412-L detect the correlation of the pixels values of the pixels at positions in the multiple sets, supplied from each of the pixel selecting unit 411-1 through pixel selecting unit 411-L. For example, the estimated error calculating unit 412-1

20 through estimated error calculating unit 412-L calculates, as a value indicating the correlation, the sum of absolute values of difference between the pixel values of the pixels of the set containing the pixel of interest, and the pixel values of the pixels at corresponding positions in other

25 sets, supplied from one of the pixel selecting unit 411-1

through pixel selecting unit 411-L.

More specifically, based on the pixel values of the pixels of the set containing the pixel of interest and the pixel values of the pixels of the set made up of pixels

5   belonging to one vertical row of pixels to the left side of the pixel of interest supplied from one of the pixel selecting unit 411-1 through pixel selecting unit 411-L, the estimated error calculating unit 412-1 through estimated error calculating unit 412-L calculates the difference of

10   the pixel values of the topmost pixel, then calculates the difference of the pixel values of the second pixel from the top, and so on to calculate the absolute values of difference of the pixel values in order from the top pixel, and further calculates the sum of absolute values of the

15   calculated differences. Based on the pixel values of the pixels of the set containing the pixel of interest and the pixel values of the pixels of the set made up of pixels belonging to one vertical row of pixels two to the left from the pixel of interest supplied from one of the pixel

20   selecting unit 411-1 through pixel selecting unit 411-L, the estimated error calculating unit 412-1 through estimated error calculating unit 412-L calculates the absolute values of difference of the pixel values in order from the top pixel, and calculates the sum of absolute values of the

25   calculated differences.

Then, based on the pixel values of the pixels of the
set containing the pixel of interest and the pixel values of
the pixels of the set made up of pixels belonging to one
vertical row of pixels to the right side of the pixel of
5   interest supplied from one of the pixel selecting unit 411-1
through pixel selecting unit 411-L, the estimated error
calculating unit 412-1 through estimated error calculating
unit 412-L calculates the difference of the pixel values of
the topmost pixel, then calculates the difference of the
10   pixel values of the second pixel from the top, and so on to
calculate the absolute values of difference of the pixel
values in order from the top pixel, and further calculates
the sum of absolute values of the calculated differences.
Based on the pixel values of the pixels of the set
15   containing the pixel of interest and the pixel values of the
pixels of the set made up of pixels belonging to one
vertical row of pixels two to the right from the pixel of
interest supplied from one of the pixel selecting unit 411-1
through pixel selecting unit 411-L, the estimated error
20   calculating unit 412-1 through estimated error calculating
unit 412-L calculates the absolute values of difference of
the pixel values in order from the top pixel, and calculates
the sum of absolute values of the calculated differences.

The estimated error calculating unit 412-1 through
25   estimated error calculating unit 412-L add all of the sums

of absolute values of difference of the pixel values thus
calculated, thereby calculating the aggregate of absolute
values of difference of the pixel values.

The estimated error calculating unit 412-1 through
5   estimated error calculating unit 412-L supply information
indicating the detected correlation to the smallest error
angle selecting unit 413. For example, the estimated error
calculating unit 412-1 through estimated error calculating
unit 412-L supply the aggregate of absolute values of
10   difference of the pixel values calculated, to the smallest
error angle selecting unit 413.

Note that the estimated error calculating unit 412-1
through estimated error calculating unit 412-L are not
restricted to the sum of absolute values of difference of
15   pixel values, and can also calculate other values as
correlation values as well, such as the sum of squared
differences of pixel values, or correlation coefficients
based on pixel values, and so forth.

The smallest error angle selecting unit 413 detects the
20   data continuity angle based on the reference axis in the
input image which corresponds to the continuity of the image
which is the lost actual world 1 light signals, based on the
correlation detected by the estimated error calculating unit
412-1 through estimated error calculating unit 412-L with
25   regard to mutually different angles. That is to say, based

on the correlation detected by the estimated error

calculating unit 412-1 through estimated error calculating

unit 412-L with regard to mutually different angles, the

smallest error angle selecting unit 413 selects the greatest

5   correlation, and takes the angle regarding which the

selected correlation was detected as the data continuity

angle based on the reference axis, thereby detecting the

data continuity angle based on the reference axis in the

input image.

10   For example, of the aggregates of absolute values of

difference of the pixel values supplied from the estimated

error calculating unit 412-1 through estimated error

calculating unit 412-L, the smallest error angle selecting

unit 413 selects the smallest aggregate. With regard to the

15   pixel set of which the selected aggregate was calculated,

the smallest error angle selecting unit 413 makes reference

to a pixel belonging to the one vertical row of pixels two

to the left from the pixel of interest and at the closest

pixel position to the straight line, and to a pixel

20   belonging to the one vertical row of pixels two to the right

from the pixel of interest and at the closest pixel position

to the straight line.

As shown in Fig. 54, the smallest error angle selecting

unit 413 obtains the distance S in the vertical direction of

25   the position of the pixels to reference from the position of

the pixel of interest. As shown in Fig. 55, the smallest

error angle selecting unit 413 detects the angle θ of data

continuity based on the axis indicating the spatial

direction X which is the reference axis in the input image

5 which is image data, that corresponds to the lost actual

world 1 light signals continuity, from Expression (37).

$$\theta = \tan^{-1}\frac{S}{2}$$

...(37)

Next, description will be made regarding the processing

10 of the pixel selecting unit 411-1 through pixel selecting

unit 411-L in the event that the data continuity angle

indicated by the activity information is a value of any from

0 degrees to 45 degrees and 135 degrees to 180 degrees.

The pixel selecting unit 411-1 through pixel selecting

15 unit 411-L set straight lines of predetermined angles which

pass through the pixel of interest, with the axis indicating

the spatial direction X as the reference axis, and select,

of the pixels belonging to a horizontal row of pixels to

which the pixel of interest belongs, a predetermined number

20 of pixels to the left of the pixel of interest, and

predetermined number of pixels to the right of the pixel of

interest, and the pixel of interest, as a pixel set.

The pixel selecting unit 411-1 through pixel selecting

unit 411-L select, from pixels belonging to a horizontal row

of pixels above the horizontal row of pixels to which the

pixel of interest belongs, a pixel at the position closest

to the straight line set for each. The pixel selecting unit

411-1 through pixel selecting unit 411-L then select, from

5   the pixels belonging to the horizontal row of pixels above

the horizontal row of pixels to which the pixel of interest

belongs, a predetermined number of pixels to the left of the

selected pixel, a predetermined number of pixels to the

right of the selected pixel, and the selected pixel, as a

10   pixel set.

The pixel selecting unit 411-1 through pixel selecting

unit 411-L select, from pixels belonging to a horizontal row

of pixels two above the horizontal row of pixels to which

the pixel of interest belongs, a pixel at the position

15   closest to the straight line set for each. The pixel

selecting unit 411-1 through pixel selecting unit 411-L then

select, from the pixels belonging to the horizontal row of

pixels two above the horizontal row of pixels to which the

pixel of interest belongs, a predetermined number of pixels

20   to the left of the selected pixel, a predetermined number of

pixels to the right of the selected pixel, and the selected

pixel, as a pixel set.

The pixel selecting unit 411-1 through pixel selecting

unit 411-L select, from pixels belonging to a horizontal row

25   of pixels below the horizontal row of pixels to which the

pixel of interest belongs, a pixel at the position closest to the straight line set for each. The pixel selecting unit 411-1 through pixel selecting unit 411-L then select, from the pixels belonging to the horizontal row of pixels below

5 the horizontal row of pixels to which the pixel of interest belongs, a predetermined number of pixels to the left of the selected pixel, a predetermined number of pixels to the right of the selected pixel, and the selected pixel, as a pixel set.

10 The pixel selecting unit 411-1 through pixel selecting unit 411-L select, from pixels belonging to a horizontal row of pixels two below the horizontal row of pixels to which the pixel of interest belongs, a pixel at the position closest to the straight line set for each. The pixel

15 selecting unit 411-1 through pixel selecting unit 411-L then select, from the pixels belonging to the horizontal row of pixels two below the horizontal row of pixels to which the pixel of interest belongs, a predetermined number of pixels to the left of the selected pixel, a predetermined number of

20 pixels to the right of the selected pixel, and the selected pixel, as a pixel set.

Thus, the pixel selecting unit 411-1 through pixel selecting unit 411-L each select five sets of pixels.

The pixel selecting unit 411-1 through pixel selecting

25 unit 411-L select pixel sets for mutually different angles.

For example, the pixel selecting unit 411-1 selects sets of
pixels regarding 0 degrees, the pixel selecting unit 411-2
selects sets of pixels regarding 2.5 degrees, and the pixel
selecting unit 411-3 selects sets of pixels regarding 5
degrees.   The pixel selecting unit 411-1 through pixel
selecting unit 411-L select sets of pixels regarding angles
every 2.5 degrees, from 7.5 degrees through 45 degrees and
from 135 degrees through 180 degrees.

The pixel selecting unit 411-1 supplies the selected
set of pixels to the estimated error calculating unit 412-1,
and the pixel selecting unit 411-2 supplies the selected set
of pixels to the estimated error calculating unit 412-2.   In
the same way, each pixel selecting unit 411-3 through pixel
selecting unit 411-L supplies the selected set of pixels to
each estimated error calculating unit 412-3 through
estimated error calculating unit 412-L.

The estimated error calculating unit 412-1 through
estimated error calculating unit 412-L detect the
correlation of the pixels values of the pixels at positions
in the multiple sets, supplied from each of the pixel
selecting unit 411-1 through pixel selecting unit 411-L.
The estimated error calculating unit 412-1 through estimated
error calculating unit 412-L supply information indicating
the detected correlation to the smallest error angle
selecting unit 413.

The smallest error angle selecting unit 413 detects the data continuity angle based on the reference axis in the input image which corresponds to the continuity of the image which is the lost actual world 1 light signals, based on the

5   correlation detected by the estimated error calculating unit 412-1 through estimated error calculating unit 412-L.

Next, data continuity detection processing with the data continuity detecting unit 101 of which the configuration is shown in Fig. 49, corresponding to the

10   processing in step S101, will be described with reference to the flowchart in Fig. 56.

In step S401, the activity detecting unit 401 and the data selecting unit 402 select the pixel of interest which is a pixel of interest from the input image. The activity

15   detecting unit 401 and the data selecting unit 402 select the same pixel of interest. For example, the activity detecting unit 401 and the data selecting unit 402 select the pixel of interest from the input image in raster scan order.

20   In step S402, the activity detecting unit 401 detects activity with regard to the pixel of interest. For example, the activity detecting unit 401 detects activity based on the difference of pixel values of pixels aligned in the vertical direction of a block made up of a predetermined

25   number of pixels centered on the pixel of interest, and the

difference of pixel values of pixels aligned in the horizontal direction.

The activity detecting unit 401 detects activity in the spatial direction as to the pixel of interest, and supplies activity information indicating the detected results to the data selecting unit 402 and the continuity direction derivation unit 404.

In step S403, the data selecting unit 402 selects, from a row of pixels including the pixel of interest, a predetermined number of pixels centered on the pixel of interest, as a pixel set. For example, the data selecting unit 402 selects a predetermined number of pixels above or to the left of the pixel of interest, and a predetermined number of pixels below or to the right of the pixel of interest, which are pixels belonging to a vertical or horizontal row of pixels to which the pixel of interest belongs, and also the pixel of interest, as a pixel set.

In step S404, the data selecting unit 402 selects, as a pixel set, a predetermined number of pixels each from a predetermined number of pixel rows for each angle in a predetermined range based on the activity detected by the processing in step S402. For example, the data selecting unit 402 sets straight lines with angles of a predetermined range which pass through the pixel of interest, with the axis indicating the spatial direction X as the reference

axis, selects a pixel which is one or two rows away from the pixel of interest in the horizontal direction or vertical direction and which is closest to the straight line, and selects a predetermined number of pixels above or to the

5   left of the selected pixel, and a predetermined number of pixels below or to the right of the selected pixel, and the selected pixel closest to the line, as a pixel set. The data selecting unit 402 selects pixel sets for each angle.

The data selecting unit 402 supplies the selected pixel

10   sets to the error estimating unit 403.

In step S405, the error estimating unit 403 calculates the correlation between the set of pixels centered on the pixel of interest, and the pixel sets selected for each angle. For example, the error estimating unit 403

15   calculates the sum of absolute values of difference of the pixel values of the pixels of the set including the pixel of interest and the pixel values of the pixels at corresponding positions in other sets, for each angle.

The angle of data continuity may be detected based on

20   the correlation between pixel sets selected for each angle.

The error estimating unit 403 supplies the information indicating the calculated correlation to the continuity direction derivation unit 404.

In step S406, from position of the pixel set having the

25   strongest correlation based on the correlation calculated in

the processing in step S405, the continuity direction

derivation unit 404 detects the data continuity angle based

on the reference axis in the input image which is image data

that corresponds to the lost actual world 1 light signal

5   continuity. For example, the continuity direction

derivation unit 404 selects the smallest aggregate of the

aggregate of absolute values of difference of pixel values,

and detects the data continuity angle θ from the position of

the pixel set regarding which the selected aggregate has

10   been calculated.

The continuity direction derivation unit 404 outputs

data continuity information indicating the angle of the data

continuity that has been detected.

In step S407, the data selecting unit 402 determines

15   whether or not processing of all pixels has ended, and in

the event that determination is made that processing of all

pixels has not ended, the flow returns to step S401, a pixel

of interest is selected from pixels not yet taken as the

pixel of interest, and the above-described processing is

20   repeated.

In the event that determination is made in step S407

that processing of all pixels has ended, the processing ends.

Thus, the data continuity detecting unit 101 can detect

the data continuity angle based on the reference axis in the

25   image data, corresponding to the lost actual world 1 light

signal continuity.

Note that an arrangement may be made wherein the data continuity detecting unit 101 of which the configuration is shown in Fig. 49 detects activity in the spatial direction of the input image with regard to the pixel of interest which is a pixel of interest in the frame of interest which is a frame of interest, extracts multiple pixel sets made up of a predetermined number of pixels in one row in the vertical direction or one row in the horizontal direction from the frame of interest and from each of frames before or after time-wise the frame of interest, for each angle and movement vector based on the pixel of interest and the space-directional reference axis, according to the detected activity, detects the correlation of the extracted pixel sets, and detects the data continuity angle in the time direction and spatial direction in the input image, based on this correlation.

For example, as shown in Fig. 57, the data selecting unit 402 extracts multiple pixel sets made up of a predetermined number of pixels in one row in the vertical direction or one row in the horizontal direction from frame #n which is the frame of interest, frame #n-1, and frame #n+1, for each angle and movement vector based on the pixel of interest and the space-directional reference axis, according to the detected activity.

The frame #n-1 is a frame which is previous to the frame #n time-wise, and the frame #n+1 is a frame following the frame #n time-wise. That is to say, the frame #n-1, frame #n, and frame #n+1, are displayed in the order of

5 frame #n-1, frame #n, and frame #n+1.

The error estimating unit 403 detects the correlation of pixel sets for each single angle and single movement vector, with regard to the multiple sets of the pixels that have been extracted. The continuity direction derivation

10 unit 404 detects the data continuity angle in the temporal direction and spatial direction in the input image which corresponds to the lost actual world 1 light signal continuity, based on the correlation of pixel sets, and outputs the data continuity information indicating the angle.

15 Next, description will be made regarding another embodiment example of the actual world estimating unit 102 (Fig. 3) with reference to Fig. 58 through Fig. 88.

Fig. 58 is a diagram for describing the principle of this embodiment example.

20 As shown in Fig. 58, a signal (light intensity allocation) in the actual world 1, which is an image cast on the sensor 2, is represented with a predetermined function F. Note that hereafter, with the description of this embodiment example, the signal serving as an image in the actual world

25 1 is particularly referred to as a light signal, and the

function F is particularly referred to as a light signal function F.

With this embodiment example, in the event that the light signal in the actual world 1 represented with the
5   light signal function F has predetermined continuity, the actual world estimating unit 102 estimates the light signal function F by approximating the light signal function F with a predetermined function f using an input image (image data including continuity of data corresponding to continuity)
10   from the sensor 2, and data continuity information (data continuity information corresponding to continuity of the input image data) from the data continuity detecting unit 101. Note that with the description of this embodiment example, the function f is particularly referred to as an
15   approximation function f, hereafter.

In other words, with this embodiment example, the actual world estimating unit 102 approximates (describes) the image (light signal in the actual world 1) represented with the light signal function F using a model 161 (Fig. 4)
20   represented with the approximation function f. Accordingly, hereafter, this embodiment example is referred to as a function approximating method.

Now, description will be made regarding the background wherein the present applicant has invented the function
25   approximating method, prior to entering the specific

description of the function approximating method.

Fig. 59 is a diagram for describing integration effects in the case in which the sensor 2 is treated as a CCD.

As shown in Fig. 59, multiple detecting elements 2-1
5   are disposed on the plane of the sensor 2.

With the example in Fig. 59, a direction in parallel with a predetermined side of the detecting elements 2-1 is taken as the X direction, which is one direction in the spatial direction, and the a direction orthogonal to the X
10 direction is taken as the Y direction, which is another direction in the spatial direction. Also, the direction perpendicular to the X-Y plane is taken as the direction t serving as the temporal direction.

Also, with the example in Fig. 59, the spatial shape of
15 each detecting element 2-1 of the sensor 2 is represented with a square of which one side is 1 in length. The shutter time (exposure time) of the sensor 2 is represented with 1.

Further, with the example in Fig. 59, the center of one detecting element 2-1 of the sensor 2 is taken as the origin
20 (position x = 0 in the X direction, and position y = 0 in the Y direction) in the spatial direction (X direction and Y direction), and the intermediate point-in-time of the exposure time is taken as the origin (position t = 0 in the t direction) in the temporal direction (t direction).

25   In this case, the detecting element 2-1 of which the

center is in the origin (x = 0, y = 0) in the spatial

direction subjects the light signal function F(x, y, t) to

integration with a range between -0.5 and 0.5 in the X

direction, range between -0.5 and 0.5 in the Y direction,

5   and range between -0.5 and 0.5 in the t direction, and

outputs the integral value thereof as a pixel value P.

That is to say, the pixel value P output from the

detecting element 2-1 of which the center is in the origin

in the spatial direction is represented with the following

10   Expression (38).

$$P = \int_{-0.5}^{+0.5} \int_{-0.5}^{+0.5} \int_{-0.5}^{+0.5} F(x, y, t) \, dx \, dy \, dt$$

...(38)

The other detecting elements 2-1 also output the pixel

value P shown in Expression (38) by taking the center of the

15   subject detecting element 2-1 as the origin in the spatial

direction in the same way.

Fig. 60 is a diagram for describing a specific example

of the integration effects of the sensor 2.

In Fig. 60, the X direction and Y direction represent

20   the X direction and Y direction of the sensor 2 (Fig. 59).

A portion 2301 of the light signal in the actual world

1 (hereafter, such a portion is referred to as a region)

represents an example of a region having predetermined

continuity.

Note that the region 2301 is a portion of the
continuous light signal (continuous region). On the other
hand, in Fig. 60, the region 2301 is shown as divided into
20 small regions (square regions) in reality. This is

5   because of representing that the size of the region 2301 is
equivalent to the size wherein the four detecting elements
(pixels) of the sensor 2 in the X direction, and also the
five detecting elements (pixels) of the sensor 2 in the Y
direction are arrayed. That is to say, each of the 20 small

10   regions (virtual regions) within the region 2301 is
equivalent to one pixel.

Also, a white portion shown in the drawing within the
region 2301 represents a light signal corresponding to a
fine line. Accordingly, the region 2301 has continuity in

15   the direction wherein a fine line continues. Hereafter, the
region 2301 is referred to as the fine-line-including actual
world region 2301.

In this case, when the fine-line-including actual world
region 2301 (a portion of a light signal in the actual world

20   1) is detected by the sensor 2, region 2302 (hereafter, this
is referred to as a fine-line-including data region 2302) of
the input image (pixel values) is output from the sensor 2
by integration effects.

Note that each pixel of the fine-line-including data

25   region 2302 is represented as an image in the drawing, but

is data representing a predetermined value in reality. That
is to say, the fine-line-including actual world region 2301
is changed (distorted) to the fine-line-including data
region 2302, which is divided into 20 pixels (20 pixels in

5   total of 4 pixels in the X direction and also 5 pixels in
the Y direction) each having a predetermined pixel value by
the integration effects of the sensor 2.

Fig. 61 is a diagram for describing another specific
example (example different from Fig. 60) of the integration

10   effects of the sensor 2.

In Fig. 61, the X direction and Y direction represent
the X direction and Y direction of the sensor 2 (Fig. 59).

A portion (region) 2303 of the light signal in the
actual world 1 represents another example (example different

15   from the fine-line-including actual world region 2301 in Fig.
60) of a region having predetermined continuity.

Note that the region 2303 is a region having the same
size as the fine-line-including actual world region 2301.
That is to say, the region 2303 is also a portion of the

20   continuous light signal in the actual world 1 (continuous
region) as with the fine-line-including actual world region
2301 in reality, but is shown as divided into 20 small
regions (square regions) equivalent to one pixel of the
sensor 2 in Fig. 61.

25   Also, the region 2303 includes a first portion having

predetermined first light intensity (value), and a second

portion edge having predetermined second light intensity

(value). Accordingly, the region 2303 has continuity in the

direction wherein the edges continue. Hereafter, the region

5   2303 is referred to as the two-valued-edge-including actual

world region 2303.

In this case, when the two-valued-edge-including actual

world region 2303 (a portion of the light signal in the

actual world 1) is detected by the sensor 2, a region 2304

10   (hereafter, referred to as two-valued-edge-including data

region 2304) of the input image (pixel value) is output from

the sensor 2 by integration effects.

Note that each pixel value of the two-valued-edge-

including data region 2304 is represented as an image in the

15   drawing as with the fine-line-including data region 2302,

but is data representing a predetermined value in reality.

That is to say, the two-valued-edge-including actual world

region 2303 is changed (distorted) to the two-valued-edge-

including data region 2304, which is divided into 20 pixels

20   (20 pixels in total of 4 pixels in the X direction and also

5 pixels in the Y direction) each having a predetermined

pixel value by the integration effects of the sensor 2.

Conventional image processing devices have regarded

image data output from the sensor 2 such as the fine-line-

25   including data region 2302, two-valued-edge-including data

region 2304, and the like as the origin (basis), and also have subjected the image data to the subsequent image processing. That is to say, regardless of that the image data output from the sensor 2 had been changed (distorted)

5   to data different from the light signal in the actual world 1 by integration effects, the conventional image processing devices have performed image processing on assumption that the data different from the light signal in the actual world 1 is correct.

10   As a result, the conventional image processing devices have provided a problem wherein based on the waveform (image data) of which the details in the actual world is distorted at the stage wherein the image data is output from the sensor 2, it is very difficult to restore the original

15   details from the waveform.

Accordingly, with the function approximating method, in order to solve this problem, as described above (as shown in Fig. 58), the actual world estimating unit 102 estimates the light signal function F by approximating the light signal

20   function F(light signal in the actual world 1) with the approximation function f based on the image data (input image) such as the fine-line-including data region 2302, and two-valued-edge-including data region 2304 output from the sensor 2.

25   Thus, at a later stage than the actual world estimating

unit 102 (in this case, the image generating unit 103 in Fig. 3), the processing can be performed by taking the image data wherein integration effects are taken into consideration, i.e., image data that can be represented with the

5 approximation function f as the origin.

Hereafter, description will be made independently regarding three specific methods (first through third function approximating methods), of such a function approximating method with reference to the drawings.

10 First, description will be made regarding the first function approximating method with reference to Fig. 62 through Fig. 76.

Fig. 62 is a diagram representing the fine-line-including actual world region 2301 shown in Fig. 60

15 described above again.

In Fig. 62, the X direction and Y direction represent the X direction and Y direction of the sensor 2 (Fig. 59).

The first function approximating method is a method for approximating a one-dimensional waveform (hereafter, such a

20 waveform is referred to as an X cross-sectional waveform $F(x)$) wherein the light signal function $F(x, y, t)$ corresponding to the fine-line-including actual world region 2301 such as shown in Fig. 62 is projected in the X direction (direction of an arrow 2311 in the drawing), with

25 the approximation function $f(x)$ serving as an n-dimensional

(n is an arbitrary integer) polynomial, for example. Accordingly, hereafter, the first function approximating method is particularly referred to as a one-dimensional approximating method.

5   Note that with the one-dimensional approximating method, the X cross-sectional waveform F(x), which is to be approximated, is not restricted to a waveform corresponding to the fine-line-including actual world region 2301 in Fig. 62, of course. That is to say, as described later, with the

10   one-dimensional approximating method, any waveform can be approximated as long as the X cross-sectional waveform F(x) corresponds to the light signals in the actual world 1 having continuity.

Also, the direction of the projection of the light

15   signal function F(x, y, t) is not restricted to the X direction, or rather the Y direction or t direction may be employed. That is to say, with the one-dimensional approximating method, a function F(y) wherein the light signal function F(x, y, t) is projected in the Y direction

20   may be approximated with a predetermined approximation function f(y), or a function F(t) wherein the light signal function F(x, y, t) is projected in the t direction may be approximated with a predetermined approximation function f (t).

25   More specifically, the one-dimensional approximating

method is a method for approximating, for example, the X

cross-sectional waveform F(x) with the approximation

function f(x) serving as an n-dimensional polynomial such as

shown in the following Expression (39).

$$f(x) = w_0 + w_1 x + w_2 x + \cdots + w_n x^n = \sum_{i=0}^{n} w_i x^i$$

$$\dots (39)$$

That is to say, with the one-dimensional approximating

method, the actual world estimating unit 102 estimates the X

cross-sectional waveform F(x) by calculating the coefficient

(features) w_i of x^i in Expression (39).

This calculation method of the features w_i is not

restricted to a particular method, for example, the

following first through third methods may be employed.

That is to say, the first method is a method that has

been employed so far.

On the other hand, the second method is a method that

has been newly invented by the present applicant, which is a

method that considers continuity in the spatial direction as

to the first method.

However, as described later, with the first and second

methods, the integration effects of the sensor 2 are not

taken into consideration. Accordingly, an approximation

function f(x) obtained by substituting the features w_i

calculated by the first method or the second method for the

above Expression (39) is an approximation function regarding

an input image, but strictly speaking, cannot be referred to

as the approximation function of the X cross-sectional

waveform $F(x)$.

5   Consequently, the present applicant has invented the

third method that calculates the features w_i further in

light of the integration effects of the sensor 2 as to the

second method. An approximation function $f(x)$ obtained by

substituting the features w_i calculated with this third

10   method for the above Expression (39) can be referred to as

the approximation function of the X cross-sectional waveform

$F(x)$ in that the integration effects of the sensor 2 are

taken into consideration.

Thus, strictly speaking, the first method and the

15   second method cannot be referred to as the one-dimensional

approximating method, and the third method alone can be

referred to as the one-dimensional approximating method.

In other words, as shown in Fig. 63, the second method

is different from the one-dimensional approximating method.

20   That is to say, Fig. 63 is a diagram for describing the

principle of the embodiment corresponding to the second

method.

As shown in Fig. 63, with the embodiment corresponding

to the second method, in the event that the light signal in

25   the actual world 1 represented with the light signal

function F has predetermined continuity, the actual world

estimating unit 102 does not approximate the X cross-

sectional waveform F(x) with an input image (image data

including continuity of data corresponding to continuity)

5   from the sensor 2, and data continuity information (data

continuity information corresponding to continuity of input

image data) from the data continuity detecting unit 101, but

approximates the input image from the sensor 2 with a

predetermined approximation function f_2 (x).

10   Thus, it is hard to say that the second method is a

method having the same level as the third method in that

approximation of the input image alone is performed without

considering the integral effects of the sensor 2. However,

the second method is a method superior to the conventional

15   first method in that the second method takes continuity in

the spatial direction into consideration.

Hereafter, description will be made independently

regarding the details of the first method, second method,

and third method in this order.

20   Note that hereafter, in the event that the respective

approximation functions f (x) generated by the first method,

second method, and third method are distinguished from that

of the other method, they are particularly referred to as

approximation function f_1 (x), approximation function f_2 (x),

25   and approximation function f_3 (x) respectively.

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First, description will be made regarding the details
of the first method.

With the first method, on condition that the
approximation function $f_1(x)$ shown in the above Expression

5 (39) holds within the fine-line-including actual world
region 2301 in Fig. 64, the following prediction equation
(40) is defined.

$$P(x, y) = f_1(x) + e$$

...(40)

10 In Expression (40), x represents a pixel position
relative as to the X direction from a pixel of interest. y
represents a pixel position relative as to the Y direction
from the pixel of interest. e represents a margin of error.
Specifically, for example, as shown in Fig. 64, let us say

15 that the pixel of interest is the second pixel in the X
direction from the left, and also the third pixel in the Y
direction from the bottom in the drawing, of the fine-line-
including data region 2302 (data of which the fine-line-
including·actual world region 2301 (Fig. 62) is detected by

20 the sensor 2, and output). Also, let us say that the center
of the pixel of interest is the origin (0, 0), and a
coordinates system (hereafter, referred to as a pixel-of-
interest coordinates system) of which axes are an x axis and
y axis respectively in parallel with the X direction and Y

25 direction of the sensor 2 (Fig. 59) is set. In this case,

the coordinates value (x, y) of the pixel-of-interest

coordinates system represents a relative pixel position.

Also, in Expression (40), P (x, y) represents a pixel

value in the relative pixel positions (x, y). Specifically,

5   in this case, the P (x, y) within the fine-line-including

data region 2302 is such as shown in Fig. 65.

Fig. 65 represents this pixel value P (x, y) in a

graphic manner.

In Fig. 65, the respective vertical axes of the graphs

10   represent pixel values, and the horizontal axes represent a

relative position x in the X direction from the pixel of

interest. Also, in the drawing, the dashed line in the

first graph from the top represents an input pixel value P

(x, -2), the broken triple-dashed line in the second graph

15   from the top represents an input pixel value P (x, -1), the

solid line in the third graph from the top represents an

input pixel value P (x, 0), the broken line in the fourth

graph from the top represents an input pixel value P (x, 1),

and the broken double-dashed line in the fifth graph from

20   the top (the first from the bottom) represents an input

pixel value P (x, 2) respectively.

Upon the 20 input pixel values P (x, -2), P (x, -1), P

(x, 0), P (x, 1), and P (x, 2) (however, x is any one

integer value of -1 through 2) shown in Fig. 65 being

25   substituted for the above Expression (40) respectively, 20

equations as shown in the following Expression (41) are
generated. Note that each e_k (k is any one of integer
values 1 through 20) represents a margin of error.

$$P(-1, -2) = f_1(-1) + e_1$$
$$P(0, -2) = f_1(0) + e_2$$
$$P(1, -2) = f_1(1) + e_3$$
$$P(2, -2) = f_1(2) + e_4$$
$$P(-1, -1) = f_1(-1) + e_5$$
$$P(0, -1) = f_1(0) + e_6$$
$$P(1, -1) = f_1(1) + e_7$$
$$P(2, -1) = f_1(2) + e_8$$
$$P(-1, 0) = f_1(-1) + e_9$$
$$P(0, 0) = f_1(0) + e_{10}$$
$$P(1, 0) = f_1(1) + e_{11}$$
$$P(2, 0) = f_1(2) + e_{12}$$
$$P(-1, 1) = f_1(-1) + e_{13}$$
$$P(0, 1) = f_1(0) + e_{14}$$
$$P(1, 1) = f_1(1) + e_{15}$$
$$P(2, 1) = f_1(2) + e_{16}$$
$$P(-1, 2) = f_1(-1) + e_{17}$$
$$P(0, 2) = f_1(0) + e_{18}$$
$$P(1, 2) = f_1(1) + e_{19}$$
$$P(2, 2) = f_1(2) + e_{20}$$

5   ...(41)

Expression (41) is made up of 20 equations, so in the
event that the number of the features w_i of the
approximation function $f_1(x)$ is less than 20, i.e., in the
event that the approximation function $f_1(x)$ is a polynomial
10   having the number of dimensions less than 19, the features
w_i can be calculated using the least square method, for

example. Note that the specific solution of the least

square method will be described later.

For example, if we say that the number of dimensions of

the approximation function $f_1(x)$ is five, the approximation

function $f_1(x)$ calculated with the least square method

using Expression (41) (the approximation function $f_1(x)$

generated by the calculated features w_i) becomes a curve

shown in Fig. 66.

Note that in Fig. 66, the vertical axis represents

pixel values, and the horizontal axis represents a relative

position x from the pixel of interest.

That is to say, for example, if we supplement the

respective 20 pixel values P (x, y) (the respective input

pixel values P (x, -2), P (x, -1), P (x, 0), P (x, 1), and P

(x, 2) shown in Fig. 65) making up the fine-line-including

data region 2302 in Fig. 64 along the x axis without any

modification (if we regard a relative position y in the Y

direction as constant, and overlay the five graphs shown in

Fig. 65), multiple lines (dashed line, broken triple-dashed

line, solid line, broken line, and broken double-dashed

line) in parallel with the x axis, such as shown in Fig. 66,

are distributed.

However, in Fig. 66, the dashed line represents the

input pixel value P (x, -2), the broken triple-dashed line

represents the input pixel value P (x, -1), the solid line

represents the input pixel value P (x, 0), the broken line

represents the input pixel value P (x, 1), and the broken

double-dashed line represents the input pixel value P (x, 2)

respectively. Also, in the event of the same pixel value,

5   lines more than 2 lines are overlaid in reality, but in Fig.

66, the lines are drawn so as to distinguish each line, and

so as not to overlay each line.

The respective 20 input pixel values (P (x, -2), P (x,

-1), P (x, 0), P (x, 1), and P (x, 2)) thus distributed, and

10   a regression curve (the approximation function f_1 (x)

obtained by substituting the features w_i calculated with the

least square method for the above Expression (38)) so as to

minimize the error of the value f_1 (x) become a curve

(approximation function f_1 (x)) shown in Fig. 66.

15   Thus, the approximation function f_1 (x) represents

nothing but a curve connecting in the X direction the means

of the pixel values (pixel values having the same relative

position x in the X direction from the pixel of interest) P

(x, -2), P (x, -1), P (x, 0), P (x, 1), and P (x, 2) in the

20   Y direction. That is to say, the approximation function f_1

(x) is generated without considering continuity in the

spatial direction included in the light signal.

For example, in this case, the fine-line-including

actual world region 2301 (Fig. 62) is regarded as a subject

25   to be approximated. This fine-line-including actual world

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region 2301 has continuity in the spatial direction, which

is represented with a gradient G_F, such as shown in Fig. 67.

Note that in Fig. 67, the X direction and Y direction

represent the X direction and Y direction of the sensor 2

5   (Fig. 59).

        Accordingly, the data continuity detecting unit 101

(Fig. 58) can output an angle θ (angle θ generated between

the direction of data continuity represented with a gradient

G_f corresponding to the gradient G_F, and the X direction)

10   such as shown in Fig. 67 as data continuity information

corresponding to the gradient G_F as continuity in the

spatial direction

        However, with the first method, the data continuity

information output from the data continuity detecting unit

15   101 is not employed at all.

        In other words, such as shown in Fig. 67, the direction

of continuity in the spatial direction of the fine-line-

including actual world region 2301 is a general angle θ

direction. However, the first method is a method for

20   calculating the features w_i of the approximation function f_1

(x) on assumption that the direction of continuity in the

spatial direction of the fine-line-including actual world

region 2301 is the Y direction (i.e., on assumption that the

angle θ is 90°).

25   Consequently, the approximation function f_1 (x) becomes

a function of which the waveform gets dull, and the detail

decreases than the original pixel value. In other words,

though not shown in the drawing, with the approximation

function f_1 (x) generated with the first method, the

5 waveform thereof becomes a waveform different from the

actual X cross-sectional waveform F(x).

To this end, the present applicant has invented the

second method for calculating the features w_i by further

taking continuity in the spatial direction into

10 consideration (utilizing the angle θ) as to the first method.

That is to say, the second method is a method for

calculating the features w_i of the approximation function f_2

(x) on assumption that the direction of continuity of the

fine-line-including actual world region 2301 is a general

15 angle θ direction.

Specifically, for example, the gradient G_f representing

continuity of data corresponding to continuity in the

spatial direction is represented with the following

Expression (42).

$$G_f = \tan \theta = \frac{dy}{dx}$$

20

... (42)

Note that in Expression (42), dx represents the amount

of fine movement in the X direction such as shown in Fig. 67,

dy represents the amount of fine movement in the Y direction

as to the dx such as shown in Fig. 67.

In this case, if we define the shift amount C_x (y) as shown in the following Expression (43), with the second method, an equation corresponding to Expression (40) employed in the first method becomes such as the following Expression (44).

$$C_x(y) = \frac{y}{G_f}$$

...(43)

$$P(x, y) = f_2(x - C_x(y)) + e$$

...(44)

That is to say, Expression (40) employed in the first method represents that the position x in the X direction of the pixel center position (x, y) is the same value regarding the pixel value P (x, y) of any pixel positioned in the same position. In other words, Expression (40) represents that pixels having the same pixel value continue in the Y direction (exhibits continuity in the Y direction).

On the other hand, Expression (44) employed in the second method represents that the pixel value P (x, y) of a pixel of which the center position is (x, y) is not identical to the pixel value (approximate equivalent to f_2 (x)) of a pixel positioned in a place distant from the pixel of interest (a pixel of which the center position is the origin (0, 0)) in the X direction by x, and is the same

value as the pixel value (approximate equivalent to f_2 $(x +$ C_x $(y))$ of a pixel positioned in a place further distant from the pixel thereof in the X direction by the shift amount C_x (y) (pixel positioned in a place distant from the

5   pixel of interest in the X direction by $x + C_x$ $(y))$. In other words, Expression (44) represents that pixels having the same pixel value continue in the angle θ direction corresponding to the shift amount C_x (y) (exhibits continuity in the general angle θ direction).

10   Thus, the shift amount C_x (y) is the amount of correction considering continuity (in this case, continuity represented with the gradient G_F in Fig. 67 (strictly speaking, continuity of data represented with the gradient G_f)) in the spatial direction, and Expression (44) is

15   obtained by correcting Expression (40) with the shift amount C_x (y).

In this case, upon the 20 pixel values P (x, y) (however, x is any one integer value of -1 through 2, and y is any one integer value of -2 through 2) of the fine-line-

20   including data region 2302 shown in Fig. 64 being substituted for the above Expression (44) respectively, 20 equations as shown in the following Expression (45) are generated.

$$P(-1, -2) = f_2(-1-C_x(-2)) + e_1$$
$$P(0, -2) = f_2(0-C_x(-2)) + e_2$$
$$P(1, -2) = f_2(1-C_x(-2)) + e_3$$
$$P(2, -2) = f_2(2-C_x(-2)) + e_4$$
$$P(-1, -1) = f_2(-1-C_x(-1)) + e_5$$
$$P(0, -1) = f_2(0-C_x(-1)) + e_6$$
$$P(1, -1) = f_2(1-C_x(-1)) + e_7$$
$$P(2, -1) = f_2(2-C_x(-1)) + e_8$$
$$P(-1, 0) = f_2(-1) + e_9$$
$$P(0, 0) = f_2(0) + e_{10}$$
$$P(1, 0) = f_2(1) + e_{11}$$
$$P(2, 0) = f_2(2) + e_{12}$$
$$P(-1, 1) = f_2(-1-C_x(1)) + e_{13}$$
$$P(0, 1) = f_2(0-C_x(1)) + e_{14}$$
$$P(1, 1) = f_2(1-C_x(1)) + e_{15}$$
$$P(2, 1) = f_2(2-C_x(1)) + e_{16}$$
$$P(-1, 2) = f_2(-1-C_x(2)) + e_{17}$$
$$P(0, 2) = f_2(0-C_x(2)) + e_{18}$$
$$P(1, 2) = f_2(1-C_x(2)) + e_{19}$$
$$P(2, 2) = f_2(2-C_x(2)) + e_{20}$$

. . . (45)

Expression (45) is made up of 20 equations, as with the above Expression (41). Accordingly, with the second method,

5 as with the first method, in the event that the number of the features w_i of the approximation function f_2 (x) is less than 20, i.e., the approximation function f_2 (x) is a polynomial having the number of dimensions less than 19, the features w_i can be calculated with the least square method,

10 for example. Note that the specific solution regarding the least square method will be described later.

For example, if we say that the number of dimensions of the approximation function $f_2(x)$ is five as with the first method, with the second method, the features w_i are calculated as follows.

5   That is to say, Fig. 68 represents the pixel value P (x, y) shown in the left side of Expression (45) in a graphic manner. The respective five graphs shown in Fig. 68 are basically the same as shown in Fig. 65.

As shown in Fig. 68, the maximal pixel values (pixel 10 values corresponding to fine lines) are continuous in the direction of continuity of data represented with the gradient G_f.

Consequently, with the second method, if we supplement the respective input pixel values P (x, -2), P (x, -1), P (x, 15 0), P (x, 1), and P (x, 2) shown in Fig. 68, for example, along the x axis, we supplement the pixel values after the pixel values are changed in the states shown in Fig. 69 instead of supplementing the pixel values without any modification as with the first method (let us assume that y 20 is constant, and the five graphs are overlaid in the states shown in Fig. 68).

That is to say, Fig. 69 represents a state wherein the respective input pixel values P (x, -2), P (x, -1), P (x, 0), P (x, 1), and P (x, 2) shown in Fig. 68 are shifted by the 25 shift amount C_x (y) shown in the above Expression (43). In

other words, Fig. 69 represents a state wherein the five

graphs shown in Fig. 68 are moved as if the gradient G_F

representing the actual direction of continuity of data were

regarded as a gradient G_F' (in the drawing, a straight line

5   made up of a dashed line were regarded as a straight line

made up of a solid line).

In the states in Fig. 69, if we supplement the

respective input pixel values P (x, -2), P (x, -1), P (x, 0),

P (x, 1), and P (x, 2), for example, along the x axis (in

10 the states shown in Fig. 69, if we overlay the five graphs),

multiple lines (dashed line, broken triple-dashed line,

solid line, broken line, and broken double-dashed line) in

parallel with the x axis, such as shown in Fig. 70, are

distributed.

15 Note that in Fig. 70, the vertical axis represents

pixel values, and the horizontal axis represents a relative

position x from the pixel of interest. Also, the dashed

line represents the input pixel value P (x, -2), the broken

triple-dashed line represents the input pixel value P (x, -

20 1), the solid line represents the input pixel value P (x, 0),

the broken line represents the input pixel value P (x, 1),

and the broken double-dashed line represents the input pixel

value P (x, 2) respectively. Further, in the event of the

same pixel value, lines more than 2 lines are overlaid in

25 reality, but in Fig. 70, the lines are drawn so as to

distinguish each line, and so as not to overlay each line.

The respective 20 input pixel values P (x, y) (however, x is any one integer value of -1 through 2, and y is any one integer value of -2 through 2) thus distributed, and a

5   regression curve (the approximation function f_2 (x) obtained by substituting the features w_i calculated with the least square method for the above Expression (38)) to minimize the error of the value f_2 (x + C_x (y)) become a curve f_2 (x) shown in the solid line in Fig. 70.

10   Thus, the approximation function f_2 (x) generated with the second method represents a curve connecting in the X direction the means of the input pixel values P (x, y) in the angle θ direction (i.e., direction of continuity in the general spatial direction) output from the data continuity

15   detecting unit 101 (Fig. 58).

On the other hand, as described above, the approximation function f_1 (x) generated with the first method represents nothing but a curve connecting in the X direction the means of the input pixel values P (x, y) in

20   the Y direction (i.e., the direction different from the continuity in the spatial direction).

Accordingly, as shown in Fig. 70, the approximation function f_2 (x) generated with the second method becomes a function wherein the degree of dullness of the waveform

25   thereof decreases, and also the degree of decrease of the

detail as to the original pixel value decreases less than
the approximation function $f_1(x)$ generated with the first
method. In other words, though not shown in the drawing,
with the approximation function $f_2(x)$ generated with the

5   second method, the waveform thereof becomes a waveform
closer to the actual X cross-sectional waveform $F(x)$ than
the approximation function $f_1(x)$ generated with the first
method.

However, as described above, the approximation function

10   $f_2(x)$ is a function considering continuity in the spatial
direction, but is nothing but a function generated wherein
the input image (input pixel value) is regarded as the
origin (basis). That is to say, as shown in Fig. 63
described above, the approximation function $f_2(x)$ is

15   nothing but a function that approximated the input image
different from the X cross-sectional waveform $F(x)$, and it
is hard to say that the approximation function $f_2(x)$ is a
function that approximated the X cross-sectional waveform
$F(x)$. In other words, the second method is a method for

20   calculating the features w_i on assumption that the above
Expression (44) holds, but does not take the relation in
Expression (38) described above into consideration (does not
consider the integration effects of the sensor 2).

Consequently, the present applicant has invented the

25   third method that calculates the features w_i of the

approximation function f_3 (x) by further taking the
integration effects of the sensor 2 into consideration as to
the second method.

That is to say, the third method is a method that
5   introduces the concept of a spatial mixture or time mixture.
Now, considering both spatial mixture and time mixture will
complicate the description, so only spatial mixture will be
considered here of spatial mixture and time mixture, and
time mixture will be ignored.

10   Description will be made regarding spatial mixture with
reference to Fig. 71 prior to description of the third
method.

In Fig. 71, a portion 2321 (hereafter, referred to as a
region 2321) of a light signal in the actual world 1
15   represents a region having the same area as one detecting
element (pixel) of the sensor 2.

Upon the sensor 2 detecting the region 2321, the sensor
2 outputs a value (one pixel value) 2322 obtained by the
region 2321 being subjected to integration in the temporal
20   and spatial directions (X direction, Y direction, and t
direction). Note that the pixel value 2322 is represented
as an image in the drawing, but is actually data
representing a predetermined value.

The region 2321 in the actual world 1 is clearly
25   classified into a light signal (white region in the drawing)

corresponding to the foreground (the above fine line, for example), and a light signal (black region in the drawing) corresponding to the background.

On the other hand, the pixel value 2322 is a value obtained by the light signal in the actual world 1 corresponding to the foreground and the light signal in the actual world 1 corresponding to the background being subjected to integration. In other words, the pixel value 2322 is a value corresponding to a level wherein the light level corresponding to the foreground and the light level corresponding to the background are spatially mixed.

Thus, in the event that a portion corresponding to one pixel (detecting element of the sensor 2) of the light signals in the actual world 1 is not a portion where the light signals having the same level are spatially uniformly distributed, but a portion where the light signals having a different level such as a foreground and background are distributed, upon the region thereof being detected by the sensor 2, the region becomes one pixel value as if the different light levels were spatially mixed by the integration effects of the sensor 2 (integrated in the spatial direction). Thus, a region made up of pixels in which an image (light signals in the actual world 1) corresponding to a foreground, and an image (light signals in the actual world 1) corresponding to a background are

subjected to spatial integration, that is, mixed as it were, which is spatial mixing, is referred to as a spatial mixed region here.

Accordingly, with the third method, the actual world

5   estimating unit 102 (Fig. 58) estimates the X cross-sectional waveform F(x) representing the original region 2321 in the actual world 1 (of the light signals in the actual world 1, the portion 2321 corresponding to one pixel of the sensor 2) by approximating the X cross-sectional

10 waveform F(x) with the approximation function f_3 (x) serving as a one-dimensional polynomial such as shown in Fig. 72.

That is to say, Fig. 72 represents an example of the approximation function f_3 (x) corresponding to the pixel value 2322 serving as a spatial mixed region (Fig. 71), i.e.,

15 the approximation function f_3 (x) that approximates the X cross-sectional waveform F(x) corresponding to the solid line within the region 2331 in the actual world 1 (Fig. 71). In Fig. 72, the axis in the horizontal direction in the drawing represents an axis in parallel with the side from

20 the upper left end x_s to lower right end x_e of the pixel corresponding to the pixel value 2322 (Fig. 71), which is taken as the x axis. The axis in the vertical direction in the drawing is taken as an axis representing pixel values.

In Fig. 72, the following Expression (46) is defined on

25 condition that the result obtained by subjecting the

approximation function f_3 (x) to integration in a range

(pixel width) from the x_s to the x_e is generally identical

with the pixel values P (x, y) output from the sensor 2

(dependent on a margin of error e alone).

$$P = \int_{x_s}^{x_e} f_3(x)\,dx + e$$
$$= \int_{x_s}^{x_e} (w_0 + w_1 x + w_2 x^2 + \cdots + w_n x^n)\,dx + e$$
$$= w_0(x_e - x_s) + \cdots + w_{n-1}\frac{x_e^n - x_s^n}{n} + w_n\frac{x_e^{n+1} - x_s^{n+1}}{n+1} + e$$

$$\cdots (46)$$

In this case, the features w_i of the approximation

function f_3 (x) are calculated from the 20 pixel values P (x,

y) (however, x is any one integer value of -1 through 2, and

y is any one integer value of -2 through 2) of the fine-

line-including data region 2302 shown in Fig. 67, so the

pixel value P in Expression (46) becomes the pixel values P

(x, y).

Also, as with the second method, it is necessary to

take continuity in the spatial direction into consideration,

and accordingly, each of the start position x_s and end

position x_e in the integral range in Expression (46) is

dependent upon the shift amount C_x (y). That is to say,

each of the start position x_s and end position x_e of the

integral range in Expression (46) is represented such as the

following Expression (47).

$$X_s = x - C_x(y) - 0.5$$
$$X_e = x - C_x(y) + 0.5$$

$$...(47)$$

In this case, upon each pixel value of the fine-line-including data region 2302 shown in Fig. 67, i.e., each of

5   the input pixel values P (x, -2), P (x, -1), P (x, 0), P (x, 1), and P (x, 2) (however, x is any one integer value of -1 through 2) shown in Fig. 68 being substituted for the above Expression (46) (the integral range is the above Expression (47)), 20 equations shown in the following Expression (48)

10   are generated.

$$P(-1, -2) = \int_{-1-C_x(-2)-0.5}^{-1-C_x(-2)+0.5} f_3(x)\,dx + e_1,$$

$$P(0, -2) = \int_{0-C_x(-2)-0.5}^{0-C_x(-2)+0.5} f_3(x)\,dx + e_2,$$

$$P(1, -2) = \int_{1-C_x(-2)-0.5}^{1-C_x(-2)+0.5} f_3(x)\,dx + e_3,$$

$$P(2, -2) = \int_{2-C_x(-2)-0.5}^{2-C_x(-2)+0.5} f_3(x)\,dx + e_4,$$

$$P(-1, -1) = \int_{-1-C_x(-1)-0.5}^{-1-C_x(-1)+0.5} f_3(x)\,dx + e_5,$$

$$P(0, -1) = \int_{0-C_x(-1)-0.5}^{0-C_x(-1)+0.5} f_3(x)\,dx + e_6,$$

$$P(1, -1) = \int_{1-C_x(-1)-0.5}^{1-C_x(-1)+0.5} f_3(x)\,dx + e_7,$$

$$P(2, -1) = \int_{2-C_x(-1)-0.5}^{2-C_x(-1)+0.5} f_3(x)\,dx + e_8,$$

$$P(-1, 0) = \int_{-1-0.5}^{-1+0.5} f_3(x)\,dx + e_9,$$

$$P(0, 0) = \int_{0-0.5}^{0+0.5} f_3(x)\,dx + e_{10},$$

$$P(1,0) = \int_{1-0.5}^{1+0.5} f_3(x)\,dx + e_{11},$$

$$P(2,0) = \int_{2-0.5}^{2+0.5} f_3(x)\,dx + e_{12},$$

$$P(-1,1) = \int_{-1-C_x(1)-0.5}^{-1-C_x(1)+0.5} f_3(x)\,dx + e_{13},$$

$$P(0,1) = \int_{0-C_x(1)-0.5}^{0-C_x(1)+0.5} f_3(x)\,dx + e_{14},$$

$$P(1,1) = \int_{1-C_x(1)-0.5}^{1-C_x(1)+0.5} f_3(x)\,dx + e_{15},$$

$$P(2,1) = \int_{2-C_x(1)-0.5}^{2-C_x(1)+0.5} f_3(x)\,dx + e_{16},$$

$$P(-1,2) = \int_{-1-C_x(2)-0.5}^{-1-C_x(2)+0.5} f_3(x)\,dx + e_{17},$$

$$P(0,2) = \int_{0-C_x(2)-0.5}^{0-C_x(2)+0.5} f_3(x)\,dx + e_{18},$$

$$P(1,2) = \int_{1-C_x(2)-0.5}^{1-C_x(2)+0.5} f_3(x)\,dx + e_{19},$$

$$P(2,2) = \int_{2-C_x(2)-0.5}^{2-C_x(2)+0.5} f_3(x)\,dx + e_{20}$$

$$\ldots (48)$$

Expression (48) is made up of 20 equations as with the above Expression (45). Accordingly, with the third method

5 as with the second method, in the event that the number of the features w_i of the approximation function f_3 (x) is less than 20, i.e., in the event that the approximation function f_3 (x) is a polynomial having the number of dimensions less than 19, for example, the features w_i may be calculated with

10 the least square method. Note that the specific solution of

the least square method will be described later.

For example, if we say that the number of dimensions of the approximation function $f_3(x)$ is five, the approximation function $f_3(x)$ calculated with the least square method using Expression (48) (the approximation function $f_3(x)$ generated with the calculated features w_i) becomes a curve shown with the solid line in Fig. 73.

Note that in Fig. 73, the vertical axis represents pixel values, and the horizontal axis represents a relative position x from the pixel of interest.

As shown in Fig. 73, in the event that the approximation function $f_3(x)$ (a curve shown with a solid line in the drawing) generated with the third method is compared with the approximation function $f_2(x)$ (a curve shown with a dashed line in the drawing) generated with the second method, a pixel value at x = 0 becomes great, and also the gradient of the curve creates a steep waveform. This is because details increase more than the input pixels, resulting in being unrelated to the resolution of the input pixels. That is to say, we can say that the approximation function $f_3(x)$ approximates the X cross-sectional waveform F(x). Accordingly, though not shown in the drawing, the approximation function $f_3(x)$ becomes a waveform closer to the X cross-sectional waveform F(x) than the approximation function $f_2(x)$.

Fig. 74 represents a configuration example of the actual world estimating unit 102 employing such a one-dimensional approximating method.

In Fig. 74, the actual world estimating unit 102 estimates the X cross-sectional waveform $F(x)$ by calculating the features w_i using the above third method (least square method) for example, and generating the approximation function $f(x)$ of the above Expression (39) using the calculated features w_i.

As shown in Fig. 74, the actual world estimating unit 102 includes a conditions setting unit 2331, input image storage unit 2332, input pixel value acquiring unit 2333, integral component calculation unit 2334, normal equation generating unit 2335, and approximation function generating unit 2336.

The conditions setting unit 2331 sets a pixel range (hereafter, referred to as a tap range) used for estimating the X cross-sectional waveform $F(x)$ corresponding to a pixel of interest, and the number of dimensions n of the approximation function $f(x)$.

The input image storage unit 2332 temporarily stores an input image (pixel values) from the sensor 2.

The input pixel value acquiring unit 2333 acquires, of the input images stored in the input image storage unit 2332, an input image region corresponding to the tap range set by

the conditions setting unit 2231, and supplies this to the normal equation generating unit 2335 as an input pixel value table. That is to say, the input pixel value table is a table in which the respective pixel values of pixels

5 included in the input image region are described. Note that a specific example of the input pixel value table will be described later.

Now, the actual world estimating unit 102 calculates the features w_i of the approximation function $f(x)$ with the

10 least square method using the above Expression (46) and Expression (47) here, but the above Expression (46) can be represented such as the following Expression (49).

$$P(x, y)$$
$$= \sum_{i=0}^{n} w_i \times \frac{(x - C_x(y) + 0.5)^{i+1} - (x - C_x(y) - 0.5)^{i+1}}{i+1} + e$$
$$= \sum_{i=0}^{n} w_i \times S_i(x_s, x_e) + e$$

$$\ldots (49)$$

15 In Expression (49), $S_i(x_s, x_e)$ represents the integral components of the i-dimensional term. That is to say, the integral components $S_i(x_s, x_e)$ are shown in the following Expression (50).

$$S_i(x_s, x_e) = \frac{x_e^{i+1} - x_s^{i+1}}{i+1}$$

20 $$\ldots (50)$$

The integral component calculation unit 2334 calculates the integral components S_i (x_s, x_e).

Specifically, the integral components S_i (x_s, x_e) (however, the value x_s and value x_e are values shown in the above Expression (46)) shown in Expression (50) may be calculated as long as the relative pixel positions (x, y), shift amount C_x (y), and i of the i-dimensional terms are known. Also, of these, the relative pixel positions (x, y) are determined by the pixel of interest and the tap range, the shift amount C_x (y) is determined by the angle θ (by the above Expression (41) and Expression (43)), and the range of i is determined by the number of dimensions n, respectively.

Accordingly, the integral component calculation unit 2334 calculates the integral components S_i (x_s, x_e) based on the tap range and the number of dimensions set by the conditions setting unit 2331, and the angle θ of the data continuity information output from the data continuity detecting unit 101, and supplies the calculated results to the normal equation generating unit 2335 as an integral component table.

The normal equation generating unit 2335 generates the above Expression (46), i.e., a normal equation in the case of obtaining the features w_i of the right side of Expression (49) with the least square method using the input pixel value table supplied from the input pixel value acquiring

unit 2333, and the integral component table supplied from the integral component calculation unit 2334, and supplies this to the approximation function generating unit 2336 as a normal equation table. Note that a specific example of a

5 normal equation will be described later.

The approximation function generating unit 2336 calculates the respective features w_i of the above Expression (49) (i.e., the respective coefficients w_i of the approximation function $f(x)$ serving as a one-dimensional

10 polynomial) by solving a normal equation included in the normal equation table supplied from the normal equation generating unit 2335 using the matrix solution, and outputs these to the image generating unit 103.

Next, description will be made regarding the actual

15 world estimating processing (processing in step S102 in Fig. 29) of the actual world estimating unit 102 (Fig. 74) which employs the one-dimensional approximating method with reference to the flowchart in Fig. 75.

For example, let us say that an input image, which is a

20 one-frame input image output from the sensor 2, including the fine-line-including data region 2302 in Fig. 60 described above has been already stored in the input image storage unit 2332. Also, let us say that the data continuity detecting unit 101 has subjected, at the

25 continuity detection processing in step S101 (Fig. 29), the

fine-line-including data region 2302 to the processing
thereof, and has already output the angle θ as data
continuity information.

In this case, the conditions setting unit 2331 sets
5　conditions (a tap range and the number of dimensions) in
step S2301 in Fig. 75.

For example, let us say that a tap range 2351 shown in
Fig. 76 is set, and 5 dimensions are set as the number of
dimensions.

10　That is to say, Fig. 76 is a diagram for describing an
example of a tap range. In Fig. 76, the X direction and Y
direction are the X direction and Y direction of the sensor
2 (Fig. 59) respectively. Also, the tap range 2351
represents a pixel group made up of 20 pixels in total (20
15　squares in the drawing) of 4 pixels in the X direction, and
also 5 pixels in the Y direction.

Further, as shown in Fig. 76, let us say that a pixel
of interest is set at the second pixel from the left and
also the third pixel from the bottom in the drawing, of the
20　tap range 2351. Also, let us say that each pixel is denoted
with a number l such as shown in Fig. 76 (l is any integer
value of 0 through 19) according to the relative pixel
positions (x, y) from the pixel of interest (a coordinate
value of a pixel-of-interest coordinates system wherein the
25　center (0, 0) of the pixel of interest is taken as the

origin).

Now, description will return to Fig. 75, wherein in step S2302, the conditions setting unit 2331 sets a pixel of interest.

5   In step S2303, the input pixel value acquiring unit 2333 acquires an input pixel value based on the condition (tap range) set by the conditions setting unit 2331, and generates an input pixel value table. That is to say, in this case, the input pixel value acquiring unit 2333

10   acquires the fine-line-including data region 2302 (Fig. 64), and generates a table made up of 20 input pixel values P (1) as an input pixel value table.

Note that in this case, the relation between the input pixel values P (1) and the above input pixel values P (x, y)

15   is a relation shown in the following Expression (51). However, in Expression (51), the left side represents the input pixel values P (1), and the right side represents the input pixel values P (x, y).

$$P(0) = P(0, 0)$$
$$P(1) = P(-1, 2)$$
$$P(2) = P(0, 2)$$
$$P(3) = P(1, 2)$$
$$P(4) = P(2, 2)$$
$$P(5) = P(-1, 1)$$
$$P(6) = P(0, 1)$$
$$P(7) = P(1, 1)$$
$$P(8) = P(2, 1)$$
$$P(9) = P(-1, 0)$$
$$P(10) = P(1, 0)$$
$$P(11) = P(2, 0)$$
$$P(12) = P(-1, -1)$$
$$P(13) = P(0, -1)$$
$$P(14) = P(1, -1)$$
$$P(15) = P(2, -1)$$
$$P(16) = P(-1, -2)$$
$$P(17) = P(0, -2)$$
$$P(18) = P(1, -2)$$
$$P(19) = P(2, -2)$$

$$\ldots (51)$$

In step S2304, the integral component calculation unit 2334 calculates integral components based on the conditions (a tap range and the number of dimensions) set by the conditions setting unit 2331, and the data continuity information (angle θ) supplied from the data continuity detecting unit 101, and generates an integral component table.

In this case, as described above, the input pixel values are not P (x, y) but P (l), and are acquired as the

value of a pixel number 1, so the integral component

calculation unit 2334 calculates the above integral

components S_i (x_s, x_e) in Expression (50) as a function of 1

such as the integral components S_i (1) shown in the left

5   side of the following Expression (52).

$$S_i (1) = S_i (x_s, x_e)$$

...(52)

Specifically, in this case, the integral components S_i

(1) shown in the following Expression (53) are calculated.

$$S_i (0) = S_i (-0.5, 0.5)$$
$$S_i (1) = S_i (-1.5-C_x (2), -0.5-C_x (2))$$
$$S_i (2) = S_i (-0.5-C_x (2), 0.5-C_x (2))$$
$$S_i (3) = S_i (0.5-C_x (2), 1.5-C_x (2))$$
$$S_i (4) = S_i (1.5-C_x (2), 2.5-C_x (2))$$
$$S_i (5) = S_i (-1.5-C_x (1), -0.5-C_x (1))$$
$$S_i (6) = S_i (-0.5-C_x (1), 0.5-C_x (1))$$
$$S_i (7) = S_i (0.5-C_x (1), 1.5-C_x (1))$$
$$S_i (8) = S_i (1.5-C_x (1), 2.5-C_x (1))$$
$$S_i (9) = S_i (-1.5, -0.5)$$
$$S_i (10) = S_i (0.5, 1.5)$$
$$S_i (11) = S_i (1.5, 2.5)$$
$$S_i (12) = S_i (-1.5-C_x (-1), -0.5-C_x (-1))$$
$$S_i (13) = S_i (-0.5-C_x (-1), 0.5-C_x (-1))$$
$$S_i (14) = S_i (0.5-C_x (-1), 1.5-C_x (-1))$$
$$S_i (15) = S_i (1.5-C_x (-1), 2.5-C_x (-1))$$
$$S_i (16) = S_i (-1.5-C_x (-2), -0.5-C_x (-2))$$
$$S_i (17) = S_i (-0.5-C_x (-2), 0.5-C_x (-2))$$
$$S_i (18) = S_i (0.5-C_x (-2), 1.5-C_x (-2))$$
$$S_i (19) = S_i (1.5-C_x (-2), 2.5-C_x (-2))$$

10

$$\cdots (53)$$

Note that in Expression (53), the left side represents the integral components S_i (l), and the right side represents the integral components S_i (x_s, x_e). That is to

5   say, in this case, i is 0 through 5, and accordingly, the 120 S_i (l) in total of the 20 S_0 (l), 20 S_1 (l), 20 S_2 (l), 20 S_3 (l), 20 S_4 (l), and 20 S_5 (l) are calculated.

More specifically, first the integral component calculation unit 2334 calculates each of the shift amounts

10   C_x (-2), C_x (-1), C_x (1), and C_x (2) using the angle θ supplied from the data continuity detecting unit 101. Next, the integral component calculation unit 2334 calculates each of the 20 integral components S_i (x_s, x_e) shown in the right side of Expression (52) regarding each of i = 0 through 5

15   using the calculated shift amounts C_x (-2), C_x (-1), C_x (1), and C_x (2). That is to say, the 120 integral components S_i (x_s, x_e) are calculated. Note that with this calculation of the integral components S_i (x_s, x_e), the above Expression (50) is used. Subsequently, the integral component

20   calculation unit 2334 converts each of the calculated 120 integral components S_i (x_s, x_e) into the corresponding integral components S_i (l) in accordance with Expression (53), and generates an integral component table including the converted 120 integral components S_i (l).

25   Note that the sequence of the processing in step S2303

and the processing in step S2304 is not restricted to the example in Fig. 75, the processing in step S2304 may be executed first, or the processing in step S2303 and the processing in step S2304 may be executed simultaneously.

5   Next, in step S2305, the normal equation generating unit 2335 generates a normal equation table based on the input pixel value table generated by the input pixel value acquiring unit 2333 at the processing in step S2303, and the integral component table generated by the integral component
10   calculation unit 2334 at the processing in step S2304.

Specifically, in this case, the features w_i of the following Expression (54) corresponding to the above Expression (49) are calculated using the least square method. A normal equation corresponding to this is represented as
15   the following Expression (55).

$$P(l) = \sum_{i=0}^{n} w_i \times S_i(l) + e$$

$$\cdots (54)$$

$$\begin{pmatrix} \sum_{l=0}^{L} S_0(l)S_0(l) & \sum_{l=0}^{L} S_0(l)S_1(l) & \cdots & \sum_{l=0}^{L} S_0(l)S_n(l) \\ \sum_{l=0}^{L} S_1(l)S_0(l) & \sum_{l=0}^{L} S_1(l)S_1(l) & \cdots & \sum_{l=0}^{L} S_1(l)S_n(l) \\ \vdots & \vdots & \ddots & \vdots \\ \sum_{l=0}^{L} S_n(l)S_0(l) & \sum_{l=0}^{L} S_n(l)S_1(l) & \cdots & \sum_{l=0}^{L} S_n(l)S_n(l) \end{pmatrix} \begin{pmatrix} w_0 \\ w_1 \\ \vdots \\ w_n \end{pmatrix} = \begin{pmatrix} \sum_{l=0}^{L} S_0(l)P(l) \\ \sum_{l=0}^{L} S_1(l)P(l) \\ \vdots \\ \sum_{l=0}^{L} S_n(l)P(l) \end{pmatrix}$$

$$\ldots (55)$$

Note that in Expression (55), L represents the maximum value of the pixel number l in the tap range. n represents the number of dimensions of the approximation function f(x)

5   serving as a polynomial. Specifically, in this case, n = 5, and L = 19.

If we define each matrix of the normal equation shown in Expression (55) as the following Expressions (56) through (58), the normal equation is represented as the following

10   Expression (59).

$$S_{MAT} = \begin{pmatrix} \sum_{l=0}^{L} S_0(l)S_0(l) & \sum_{l=0}^{L} S_0(l)S_1(l) & \cdots & \sum_{l=0}^{L} S_0(l)S_n(l) \\ \sum_{l=0}^{L} S_1(l)S_0(l) & \sum_{l=0}^{L} S_1(l)S_1(l) & \cdots & \sum_{l=0}^{L} S_1(l)S_n(l) \\ \vdots & \vdots & \ddots & \vdots \\ \sum_{l=0}^{L} S_n(l)S_0(l) & \sum_{l=0}^{L} S_n(l)S_1(l) & \cdots & \sum_{l=0}^{L} S_n(l)S_n(l) \end{pmatrix}$$

$$\ldots (56)$$

$$W_{MAT} = \begin{pmatrix} w_0 \\ w_1 \\ \vdots \\ w_n \end{pmatrix}$$

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... (57)

$$P_{MAT} = \begin{pmatrix} \sum\limits_{l=0}^{L} S_0(l)P(l) \\ \sum\limits_{l=0}^{L} S_1(l)P(l) \\ \vdots \\ \sum\limits_{l=0}^{L} S_n(l)P(l) \end{pmatrix}$$

... (58)

$$S_{MAT} W_{MAT} = P_{MAT}$$

... (59)

As shown in Expression (57), the respective components of the matrix W_{MAT} are the features w_i to be obtained. Accordingly, in Expression (59), if the matrix S_{MAT} of the left side and the matrix P_{MAT} of the right side are determined, the matrix W_{MAT} (i.e., features w_i) may be calculated with the matrix solution.

Specifically, as shown in Expression (56), the respective components of the matrix S_{MAT} may be calculated as long as the above integral components S_i (l) are known. The integral components S_i (l) are included in the integral component table supplied from the integral component calculation unit 2334, so the normal equation generating unit 2335 can calculate each component of the matrix S_{MAT} using the integral component table.

Also, as shown in Expression (58), the respective components of the matrix P_{MAT} may be calculated as long as the integral components S_i (l) and the input pixel values P (l) are known. The integral components S_i (l) is the same as those included in the respective components of the matrix S_{MAT}, also the input pixel values P (l) are included in the input pixel value table supplied from the input pixel value acquiring unit 2333, so the normal equation generating unit 2335 can calculate each component of the matrix P_{MAT} using the integral component table and input pixel value table.

Thus, the normal equation generating unit 2335 calculates each component of the matrix S_{MAT} and matrix P_{MAT}, and outputs the calculated results (each component of the matrix S_{MAT} and matrix P_{MAT}) to the approximation function generating unit 2336 as a normal equation table.

Upon the normal equation table being output from the normal equation generating unit 2335, in step S2306, the approximation function generating unit 2336 calculates the features w_i (i.e., the coefficients w_i of the approximation function f (x) serving as a one-dimensional polynomial) serving as the respective components of the matrix W_{MAT} in the above Expression (59) based on the normal equation table.

Specifically, the normal equation in the above Expression (59) can be transformed as the following Expression (60).

$$W_{MAT} = S_{MAT}^{-1}P_{MAT}$$

...(60)

In Expression (60), the respective components of the matrix W_{MAT} in the left side are the features w_i to be

5   obtained. The respective components regarding the matrix S_{MAT} and matrix P_{MAT} are included in the normal equation table supplied from the normal equation generating unit 2335. Accordingly, the approximation function generating unit 2336 calculates the matrix W_{MAT} by calculating the matrix in the

10   right side of Expression (60) using the normal equation table, and outputs the calculated results (features w_i) to the image generating unit 103.

In step S2307, the approximation function generating unit 2336 determines regarding whether or not the processing

15   of all the pixels has been completed.

In step S2307, in the event that determination is made that the processing of all the pixels has not been completed, the processing returns to step S2302, wherein the subsequent processing is repeatedly performed. That is to say, the

20   pixels that have not become a pixel of interest are sequentially taken as a pixel of interest, and the processing in step S2302 through S2307 is repeatedly performed.

In the event that the processing of all the pixels has

been completed (in step S2307, in the event that
determination is made that the processing of all the pixels
has been completed), the estimating processing of the actual
world 1 ends.

5   Note that the waveform of the approximation function
f(x) generated with the coefficients (features) w_i thus
calculated becomes a waveform such as the approximation
function $f_3(x)$ in Fig. 73 described above.

Thus, with the one-dimensional approximating method,
10   the features of the approximation function f(x) serving as a
one-dimensional polynomial are calculated under the
assumption, for example, that a waveform having the same
form as the one-dimensional X cross-sectional waveform F(x)
is continuous in the direction of continuity. Accordingly,
15   with the one-dimensional approximating method, the features
of the approximation function f(x) can be calculated with
less amount of calculation processing than other function
approximating methods.

Next, description will be made regarding the second
20   function approximating method with reference to Fig. 77
through Fig. 83.

That is to say, the second function approximating
method is a method wherein the light signal in the actual
world 1 having continuity in the spatial direction
25   represented with the gradient G_F such as shown in Fig. 77

for example is regarded as a waveform $F(x, y)$ on the X-Y

plane (on the plane level in the X direction serving as one

direction of the spatial directions, and in the Y direction

orthogonal to the X direction), and the waveform $F(x, y)$ is

5   approximated with the approximation function $f(x, y)$ serving

as a two-dimensional polynomial, thereby estimating the

waveform $F(x, y)$.   Accordingly, hereafter, the second

function approximating method is referred to as a two-

dimensional polynomial approximating method.

10   Note that in Fig. 77, the horizontal direction

represents the X direction serving as one direction of the

spatial directions, the upper right direction represents the

Y direction serving as the other direction of the spatial

directions, and the vertical direction represents the level

15   of light respectively. G_F represents the gradient as

continuity in the spatial direction.

Also, with description of the two-dimensional

polynomial approximating method, let us say that the sensor

2 is a CCD made up of the multiple detecting elements 2-1

20   disposed on the plane thereof, such as shown in Fig. 78.

With the example in Fig. 78, the direction in parallel

with a predetermined side of the detecting elements 2-1 is

taken as the X direction serving as one direction of the

spatial directions, and the direction orthogonal to the X

25   direction is taken as the Y direction serving as the other

direction of the spatial directions. The direction orthogonal to the X-Y plane is taken as the t direction serving as the temporal direction.

Also, with the example in Fig. 78, the spatial shape of
5   the respective detecting elements 2-1 of the sensor 2 is taken as a square of which one side is 1 in length. The shutter time (exposure time) of the sensor 2 is taken as 1.

Further, with the example in Fig. 78, the center of one certain detecting element 2-1 of the sensor 2 is taken as
10   the origin (the position in the X direction is x = 0, and the position in the Y direction is y = 0) in the spatial directions (X direction and Y direction), and also the intermediate point-in-time of the exposure time is taken as the origin (the position in the t direction is t = 0) in the
15   temporal direction (t direction).

In this case, the detecting element 2-1 of which the center is in the origin (x = 0, y = 0) in the spatial directions subjects the light signal function F(x, y, t) to integration with a range of -0.5 through 0.5 in the X
20   direction, with a range of -0.5 through 0.5 in the Y direction, and with a range of -0.5 through 0.5 in the t direction, and outputs the integral value as the pixel value P.

That is to say, the pixel value P output from the
25   detecting element 2-1 of which the center is in the origin

in the spatial directions is represented with the following

Expression (61).

$$P = \int_{-0.5}^{+0.5} \int_{-0.5}^{+0.5} \int_{-0.5}^{+0.5} F(x, y, t) dx dy dt$$

... (61)

5   Similarly, the other detecting elements 2-1 output the

pixel value P shown in Expression (61) by taking the center

of the detecting element 2-1 to be processed as the origin

in the spatial directions.

Incidentally, as described above, the two-dimensional

10   polynomial approximating method is a method wherein the

light signal in the actual world 1 is handled as a waveform

F(x, y) such as shown in Fig. 77 for example, and the two-

dimensional waveform F(x, y) is approximated with the

approximation function f(x, y) serving as a two-dimensional

15   polynomial.

First, description will be made regarding a method

representing such the approximation function f(x, y) with a

two-dimensional polynomial.

As described above, the light signal in the actual

20   world 1 is represented with the light signal function F(x, y,

t) of which variables are the position on the three-

dimensional space x, y, and z, and point-in-time t. This

light signal function F(x, y, t), i.e., a one-dimensional

waveform projected in the X direction at an arbitrary

position y in the Y direction is referred to as an X cross-sectional waveform F(x), here.

When paying attention to this X cross-sectional waveform F(x), in the event that the signal in the actual
5   world 1 has continuity in a certain direction in the spatial directions, it can be conceived that a waveform having the same form as the X cross-sectional waveform F(x) continues in the continuity direction. For example, with the example in Fig. 77, a waveform having the same form as the X cross-
10   sectional waveform F(x) continues in the direction of the gradient G_F. In other words, it can be said that the waveform F(x, y) is formed by a waveform having the same form as the X cross-sectional waveform F(x) continuing in the direction of the gradient G_F.

15   Accordingly, the approximation function f(x, y) can be represented with a two-dimensional polynomial by considering that the waveform of the approximation function f(x, y) approximating the waveform F(x, y) is formed by a waveform having the same form as the approximation function f(x)
20   approximating the X cross-sectional F (x) continuing.

Description will be made in more detail regarding the representing method of the approximation function f(x, y).

For example, let us say that the light signal in the actual world 1 such as shown in Fig. 77 described above,
25   i.e., a light signal having continuity in the spatial

direction represented with the gradient G_F is detected by the sensor 2 (Fig. 78), and output as an input image (pixel value).

Further, let us say that as shown in Fig. 79, the data
5   continuity detecting unit 101 (Fig. 3) subjects an input image region 2401 made up of 20 pixels (in the drawing, 20 squares represented with dashed line) in total of 4 pixels in the X direction and also 5 pixels in the Y direction, of this input image, to the processing thereof, and outputs an
10   angle θ (angle θ generated between the direction of data continuity represented with the gradient G_f corresponding to the gradient G_F, and the X direction) as one of the data continuity information.

Note that with the input image region 2401, the
15   horizontal direction in the drawing represents the X direction serving as one direction in the spatial directions, and the vertical direction in the drawing represents the Y direction serving as the other direction of the spatial directions.

20   Also, in Fig. 79, an (x, y) coordinates system is set such that a pixel in the second pixel from the left, and also the third pixel from the bottom is taken as a pixel of interest, and the center of the pixel of interest is taken as the origin (0, 0). A relative distance (hereafter,
25   referred to as a cross-sectional direction distance) in the

X direction as to the straight line (straight line having

the gradient G_f representing the direction of data

continuity) having an angle θ passing through the origin (0,

0) is described as x'.

5   Further, in Fig. 79, the graph on the right side is a

function wherein an X cross-sectional waveform F(x') is

approximated, which represents an approximation function

f(x') serving as an n-dimensional (n is an arbitrary

integer) polynomial. Of the axes in the graph on the right

10   side, the axis in the horizontal direction in the drawing

represents a cross-sectional direction distance, and the

axis in the vertical direction in the drawing represents

pixel values.

In this case, the approximation function f(x') shown in

15   Fig. 79 is an n-dimensional polynomial, so is represented as

the following Expression (62).

$$f(x') = w_0 + w_1 x' + w_2 x' + \cdots + w_n x'^n = \sum_{i=0}^{n} w_i x'^i$$

...(62)

Also, since the angle θ is determined, the straight line

20   having angle θ passing through the origin (0, 0) is uniquely

determined, and a position x_1 in the X direction of the

straight line at an arbitrary position y in the Y direction

is represented as the following Expression (63). However,

in Expression (63), s represents cot θ (= 1~□□□θ).

$$X_| = s \times y$$

$$\ldots (63)$$

That is to say, as shown in Fig. 79, a point on the straight line corresponding to continuity of data

5 represented with the gradient G_f is represented with a coordinate value (x_1, y).

The cross-sectional direction distance x' is represented as the following Expression (64) using Expression (63).

10 $$x' = x - x_| = x - s \times y$$

$$\ldots (64)$$

Accordingly, the approximation function f(x, y) at an arbitrary position (x, y) within the input image region 2401 is represented as the following Expression (65) using

15 Expression (62) and Expression (64).

$$f(x, y) = \sum_{i=0}^{n} w_i (x - s \times y)^i$$

$$\ldots (65)$$

Note that in Expression (65), w_i represents coefficients of the approximation function f(x, y). Note that the

20 coefficients w_i of the approximation function f including the approximation function f(x, y) can be evaluated as the features of the approximation function f. Accordingly, the coefficients w_i of the approximation function f are also referred to as the features w_i of the approximation function

f.

Thus, the approximation function $f(x, y)$ having a two-dimensional waveform can be represented as the polynomial of Expression (65) as long as the angle θ is known.

5   Accordingly, if the actual world estimating unit 102 can calculate the features w_i of Expression (65), the actual world estimating unit 102 can estimate the waveform $F(x, y)$ such as shown in Fig. 77.

Consequently, hereafter, description will be made

10 regarding a method for calculating the features w_i of Expression (65).

That is to say, upon the approximation function $f(x, y)$ represented with Expression (65) being subjected to integration with an integral range (integral range in the

15 spatial direction) corresponding to a pixel (the detecting element 2-1 of the sensor 2 (Fig. 78)), the integral value becomes the estimated value regarding the pixel value of the pixel. It is the following Expression (66) that this is represented with an equation. Note that with the two-

20 dimensional polynomial approximating method, the temporal direction t is regarded as a constant value, so Expression (66) is taken as an equation of which variables are the positions x and y in the spatial directions (X direction and Y direction).

$$P(x, y) = \int_{y-0.5}^{y+0.5} \int_{x-0.5}^{x+0.5} \sum_{i=0}^{n} w_i (x - s \times y)^i + e$$

$$\ldots (66)$$

In Expression (66), $P(x, y)$ represents the pixel value of a pixel of which the center position is in a position (x, y) (relative position (x, y) from the pixel of interest) of an input image from the sensor 2. Also, e represents a margin of error.

Thus, with the two-dimensional polynomial approximating method, the relation between the input pixel value $P(x, y)$ and the approximation function $f(x, y)$ serving as a two-dimensional polynomial can be represented with Expression (66), and accordingly, the actual world estimating unit 102 can estimate the two-dimensional function $F(x, y)$ (waveform $F(x, y)$ wherein the light signal in the actual world 1 having continuity in the spatial direction represented with the gradient G_F (Fig. 77) is represented focusing attention on the spatial direction) by calculating the features w_i with, for example, the least square method or the like using Expression (66) (by generating the approximation function $f(x, y)$ by substituting the calculated features w_i for Expression (64)).

Fig. 80 represents a configuration example of the actual world estimating unit 102 employing such a two-dimensional polynomial approximating method.

As shown in Fig. 80, the actual world estimating unit 102 includes a conditions setting unit 2421, input image storage unit 2422, input pixel value acquiring unit 2423, integral component calculation unit 2424, normal equation

5 generating unit 2425, and approximation function generating unit 2426.

The conditions setting unit 2421 sets a pixel range (tap range) used for estimating the function $F(x, y)$ corresponding to a pixel of interest, and the number of

10 dimensions n of the approximation function $f(x, y)$.

The input image storage unit 2422 temporarily stores an input image (pixel values) from the sensor 2.

The input pixel value acquiring unit 2423 acquires, of the input images stored in the input image storage unit 2422,

15 an input image region corresponding to the tap range set by the conditions setting unit 2421, and supplies this to the normal equation generating unit 2425 as an input pixel value table. That is to say, the input pixel value table is a table in which the respective pixel values of pixels

20 included in the input image region are described. Note that a specific example of the input pixel value table will be described later.

Incidentally, as described above, the actual world estimating unit 102 employing the two-dimensional

25 approximating method calculates the features w_i of the

approximation function f(x, y) represented with the above

Expression (65) by solving the above Expression (66) using

the least square method.

Expression (66) can be represented as the following

5 Expression (71) by using the following Expression (70)

obtained by the following Expressions (67) through (69).

$$\int x^i dx = \frac{x^{i+1}}{i+1}$$

$$...(67)$$

$$\int (x-s \times y)^i dx = \frac{(x-s \times y)^{i+1}}{(i+1)}$$

10

$$...(68)$$

$$\int (x-s \times y)^i dy = \frac{(x-s \times y)^{i+1}}{s(i+1)}$$

$$...(69)$$

$$\int_{y-0.5}^{y+0.5} \int_{x-0.5}^{x+0.5} (x-s \times y)^i dxdy = \int_{y-0.5}^{y+0.5} \left[\frac{(x-s \times y)^{i+1}}{(i+1)} \right]_{x-0.5}^{x+0.5} dy$$

$$= \int_{y-0.5}^{y+0.5} \frac{(x+0.5-s \times y)^{i+1} - (x-0.5-s \times y)^{i+1}}{i+1} dy$$

$$= \left[\frac{(x+0.5-s \times y)^{i+2}}{s(i+1)(i+2)} \right]_{y-0.5}^{y+0.5} - \left[\frac{(x-0.5-s \times y)^{i+2}}{s(i+1)(i+2)} \right]_{y-0.5}^{y+0.5}$$

$$= \frac{(x+0.5-s \times y+0.5s)^{i+2} - (x+0.5-s \times y-0.5s)^{i+2} - (x-0.5-s \times y+0.5s)^{i+2} + (x-0.5-s \times y-0.5s)^{i+2}}{s(i+1)(i+2)}$$

$$...(70)$$

$$P(x, y) = \sum_{i=0}^{n} \frac{w_i}{s(i+1)(i+2)} \{(x+0.5-s \times y+0.5s)^{i+2}$$

$$-(x+0.5-s \times y-0.5s)^{i+2} - (x-0.5-s \times y+0.5s)^{i+2}$$

$$+(x-0.5-s \times y-0.5s)^{i+2}\} + e$$

$$= \sum_{i=0}^{n} w_i s_i (x-0.5, x+0.5, y-0.5, y+0.5) + e$$

$$\ldots (71)$$

In Expression (71), S_i (x - 0.5, x + 0.5, y - 0.5, y + 0.5) represents the integral components of i-dimensional

5   terms. That is to say, the integral components S_i (x - 0.5, x + 0.5, y - 0.5, y + 0.5) are as shown in the following Expression (72).

$$s_i (x-0.5, x+0.5, y-0.5, y+0.5) =$$

$$\frac{(x+0.5-s \times y+0.5s)^{i+2} - (x+0.5-s \times y-0.5s)^{i+2} - (x-0.5-s \times y+0.5s)^{i+2} + (x-0.5-s \times y-0.5s)^{i+2}}{s(i+1)(i+2)}$$

$$\ldots (72)$$

10   The integral component calculation unit 2424 calculates the integral components S_i (x - 0.5, x + 0.5, y - 0.5, y + 0.5).

Specifically, the integral components S_i (x - 0.5, x + 0.5, y - 0.5, y + 0.5) shown in Expression (72) can be

15   calculated as long as the relative pixel positions (x, y), the variable s and i of i-dimensional terms in the above Expression (65) are known. Of these, the relative pixel positions (x, y) are determined with a pixel of interest,

and a tap range, the variable s is cot θ, which is determined with the angle θ, and the range of i is determined with the number of dimensions n respectively.

Accordingly, the integral component calculation unit
5 2424 calculates the integral components S_i (x - 0.5, x + 0.5, y - 0.5, y + 0.5) based on the tap range and the number of dimensions set by the conditions setting unit 2421, and the angle θ of the data continuity information output from the data continuity detecting unit 101, and supplies the
10 calculated results to the normal equation generating unit 2425 as an integral component table.

The normal equation generating unit 2425 generates a normal equation in the case of obtaining the above Expression (66), i.e., Expression (71) by the least square
15 method using the input pixel value table supplied from the input pixel value acquiring unit 2423, and the integral component table supplied from the integral component calculation unit 2424, and outputs this to the approximation function generating unit 2426 as a normal equation table.
20 Note that a specific example of a normal equation will be described later.

The approximation function generating unit 2426 calculates the respective features w_i of the above Expression (66) (i.e., the coefficients w_i of the
25 approximation function f(x, y) serving as a two-dimensional

polynomial) by solving the normal equation included in the normal equation table supplied from the normal equation generating unit 2425 using the matrix solution, and output these to the image generating unit 103.

5   Next, description will be made regarding the actual world estimating processing (processing in step S102 in Fig. 29) to which the two-dimensional polynomial approximating method is applied, with reference to the flowchart in Fig. 81.

10   For example, let us say that the light signal in the actual world 1 having continuity in the spatial direction represented with the gradient G_F has been detected by the sensor 2 (Fig. 78), and has been stored in the input image storage unit 2422 as an input image corresponding to one frame. Also, let us say that the data continuity detecting unit 101 has subjected the region 2401 shown in Fig. 79 described above of the input image to processing in the continuity detecting processing in step S101 (Fig. 29), and has output the angle θ as data continuity information.

20   In this case, in step S2401, the conditions setting unit 2421 sets conditions (a tap range and the number of dimensions).

For example, let us say that a tap range 2441 shown in Fig. 82 has been set, and also 5 has been set as the number of dimensions.

Fig. 82 is a diagram for describing an example of a tap
range. In Fig. 82, the X direction and Y direction
represent the X direction and Y direction of the sensor 2
(Fig. 78). Also, the tap range 2441 represents a pixel

5   group made up of 20 pixels (20 squares in the drawing) in
total of 4 pixels in the X direction and also 5 pixels in
the Y direction.

Further, as shown in Fig. 82, let us say that a pixel
of interest has been set to a pixel, which is the second

10 pixel from the left and also the third pixel from the bottom
in the drawing, of the tap range 2441. Also, let us say
that each pixel is denoted with a number l such as shown in
Fig. 82 (l is any integer value of 0 through 19) according
to the relative pixel positions (x, y) from the pixel of

15 interest (a coordinate value of a pixel-of-interest
coordinates system wherein the center (0, 0) of the pixel of
interest is taken as the origin).

Now, description will return to Fig. 81, wherein in
step S2402, the conditions setting unit 2421 sets a pixel of

20 interest.

In step S2403, the input pixel value acquiring unit
2423 acquires an input pixel value based on the condition
(tap range) set by the conditions setting unit 2421, and
generates an input pixel value table. That is to say, in

25 this case, the input pixel value acquiring unit 2423

acquires the input image region 2401 (Fig. 79), generates a table made up of 20 input pixel values P (l) as an input pixel value table.

5 Note that in this case, the relation between the input pixel values P (l) and the above input pixel values P (x, y) is a relation shown in the following Expression (73). However, in Expression (73), the left side represents the input pixel values P (l), and the right side represents the input pixel values P (x, y).

$$P(0) = P(0, 0)$$
$$P(1) = P(-1, 2)$$
$$P(2) = P(0, 2)$$
$$P(3) = P(1, 2)$$
$$P(4) = P(2, 2)$$
$$P(5) = P(-1, 1)$$
$$P(6) = P(0, 1)$$
$$P(7) = P(1, 1)$$
$$P(8) = P(2, 1)$$
$$P(9) = P(-1, 0)$$
$$P(10) = P(1, 0)$$
$$P(11) = P(2, 0)$$
$$P(12) = P(-1, -1)$$
$$P(13) = P(0, -1)$$
$$P(14) = P(1, -1)$$
$$P(15) = P(2, -1)$$
$$P(16) = P(-1, -2)$$
$$P(17) = P(0, -2)$$
$$P(18) = P(1, -2)$$
$$P(19) = P(2, -2)$$

10

$$\ldots (73)$$

In step S2404, the integral component calculation unit
2424 calculates integral components based on the conditions
(a tap range and the number of dimensions) set by the
conditions setting unit 2421, and the data continuity

5 information (angle θ) supplied from the data continuity
detecting unit 101, and generates an integral component
table.

In this case, as described above, the input pixel
values are not P (x, y) but P (l), and are acquired as the

10 value of a pixel number l, so the integral component
calculation unit 2424 calculates the integral components S_i
(x - 0.5, x + 0.5, y - 0.5, y + 0.5) in the above Expression
(72) as a function of l such as the integral components S_i
(l) shown in the left side of the following Expression (74).

15 $$S_i(l) = S_i(x-0.5, x+0.5, y-0.5, y+0.5)$$

...(74)

Specifically, in this case, the integral components S_i
(l) shown in the following Expression (75) are calculated.

$$S_i(0) = S_i(-0.5, 0.5, -0.5, 0.5)$$
$$S_i(1) = S_i(-1.5, -0.5, 1.5, 2.5)$$
$$S_i(2) = S_i(-0.5, 0.5, 1.5, 2.5)$$
$$S_i(3) = S_i(0.5, 1.5, 1.5, 2.5)$$
$$S_i(4) = S_i(1.5, 2.5, 1.5, 2.5)$$
$$S_i(5) = S_i(-1.5, -0.5, 0.5, 1.5)$$
$$S_i(6) = S_i(-0.5, 0.5, 0.5, 1.5)$$
$$S_i(7) = S_i(0.5, 1.5, 0.5, 1.5)$$
$$S_i(8) = S_i(1.5, 2.5, 0.5, 1.5)$$
$$S_i(9) = S_i(-1.5, -0.5, -0.5, 0.5)$$
$$S_i(10) = S_i(0.5, 1.5, -0.5, 0.5)$$
$$S_i(11) = S_i(1.5, 2.5, -0.5, 0.5)$$
$$S_i(12) = S_i(-1.5, -0.5, -1.5, -0.5)$$
$$S_i(13) = S_i(-0.5, 0.5, -1.5, -0.5)$$
$$S_i(14) = S_i(0.5, 1.5, -1.5, -0.5)$$
$$S_i(15) = S_i(1.5, 2.5, -1.5, -0.5)$$
$$S_i(16) = S_i(-1.5, -0.5, -2.5, -1.5)$$
$$S_i(17) = S_i(-0.5, 0.5, -2.5, -1.5)$$
$$S_i(18) = S_i(0.5, 1.5, -2.5, -1.5)$$
$$S_i(19) = S_i(1.5, 2.5, -2.5, -1.5)$$

...(75)

Note that in Expression (75), the left side represents the integral components S_i (l), and the right side represents the integral components S_i (x - 0.5, x + 0.5, y - 0.5, y + 0.5). That is to say, in this case, i is 0 through 5, and accordingly, the 120 S_i (l) in total of the 20 S_0 (l), 20 S_1 (l), 20 S_2 (l), 20 S_3 (l), 20 S_4 (l), and 20 S_5 (l) are calculated.

More specifically, first the integral component calculation unit 2424 calculates cot θ corresponding to the

angle θ supplied from the data continuity detecting unit 101,

and takes the calculated result as a variable s. Next, the

integral component calculation unit 2424 calculates each of

the 20 integral components S_i (x - 0.5, x + 0.5, y - 0.5, y

5   + 0.5) shown in the right side of Expression (74) regarding

each of i = 0 through 5 using the calculated variable s.

That is to say, the 120 integral components S_i (x - 0.5, x +

0.5, y - 0.5, y + 0.5) are calculated. For computing the

integration component S_i (x - 0.5, x + 0.5, y - 0.5, y +

10 0.5), the above-described Expression (72) is used. Also the

integration component computing unit 2424 converts each of

the 120 computed integration components S_i (x - 0.5, x + 0.5,

y - 0.5, y + 0.5) into the corresponding S_i (1) respectively,

according to Expression (75), and generates an integration

15 component table containing the 120 converted S_i (1).

Note that the sequence of the processing in step S2403

and the processing in step S2404 is not restricted to the

example in Fig. 81, the processing in step S2404 may be

executed first, or the processing in step S2403 and the

20 processing in step S2404 may be executed simultaneously.

Next, in step S2405, the normal equation generating

unit 2425 generates a normal equation table based on the

input pixel value table generated by the input pixel value

acquiring unit 2423 at the processing in step S2403, and the

25 integral component table generated by the integral component

calculation unit 2424 at the processing in step S2404.

Specifically, in this case, the features w_i are

calculated with the least square method using the above

Expression (71) (however, in Expression (70), the S_i (1)

5   into which the integral components S_i (x - 0.5, x + 0.5, y -

0.5, y + 0.5) are converted using Expression (74) is used),

so a normal equation corresponding to this is represented as

the following Expression (76).

$$
\begin{pmatrix}
\sum_{l=0}^{L} S_0(l)S_0(l) & \sum_{l=0}^{L} S_0(l)S_1(l) & \cdots & \sum_{l=0}^{L} S_0(l)S_n(l) \\
\sum_{l=0}^{L} S_1(l)S_0(l) & \sum_{l=0}^{L} S_1(l)S_1(l) & \cdots & \sum_{l=0}^{L} S_1(l)S_n(l) \\
\vdots & \vdots & \ddots & \vdots \\
\sum_{l=0}^{L} S_n(l)S_0(l) & \sum_{l=0}^{L} S_n(l)S_1(l) & \cdots & \sum_{l=0}^{L} S_n(l)S_n(l)
\end{pmatrix}
\begin{pmatrix}
w_0 \\
w_1 \\
\vdots \\
w_n
\end{pmatrix}
=
\begin{pmatrix}
\sum_{l=0}^{L} S_0(l)P(l) \\
\sum_{l=0}^{L} S_1(l)P(l) \\
\vdots \\
\sum_{l=0}^{L} S_n(l)P(l)
\end{pmatrix}
$$

10 $\ldots$ (76)

Note that in Expression (76), L represents the maximum

value of the pixel number l in the tap range. n represents

the number of dimensions of the approximation function f(x)

serving as a polynomial. Specifically, in this case, n = 5,

15   and L = 19.

If we define each matrix of the normal equation shown

in Expression (76) as the following Expressions (77) through

(79), the normal equation is represented as the following

Expression (80).

$$S_{MAT} = \begin{pmatrix} \sum\limits_{l=0}^{L} S_0(l)S_0(l) & \sum\limits_{l=0}^{L} S_0(l)S_1(l) & \cdots & \sum\limits_{l=0}^{L} S_0(l)S_n(l) \\ \sum\limits_{l=0}^{L} S_1(l)S_0(l) & \sum\limits_{l=0}^{L} S_1(l)S_1(l) & \cdots & \sum\limits_{l=0}^{L} S_1(l)S_n(l) \\ \vdots & \vdots & \ddots & \vdots \\ \sum\limits_{l=0}^{L} S_n(l)S_0(l) & \sum\limits_{l=0}^{L} S_n(l)S_1(l) & \cdots & \sum\limits_{l=0}^{L} S_n(l)S_n(l) \end{pmatrix}$$

$$\ldots (77)$$

$$W_{MAT} = \begin{pmatrix} w_0 \\ w_1 \\ \vdots \\ w_n \end{pmatrix}$$

$$\ldots (78)$$

$$P_{MAT} = \begin{pmatrix} \sum\limits_{l=0}^{L} S_0(l)P(l) \\ \sum\limits_{l=0}^{L} S_1(l)P(l) \\ \vdots \\ \sum\limits_{l=0}^{L} S_n(l)P(l) \end{pmatrix}$$

5

$$\ldots (79)$$

$$S_{MAT} W_{MAT} = P_{MAT}$$

$$\ldots (80)$$

As shown in Expression (78), the respective components of the matrix W_{MAT} are the features w_i to be obtained. Accordingly, in Expression (80), if the matrix S_{MAT} of the

5   left side and the matrix P_{MAT} of the right side are determined, the matrix W_{MAT} may be calculated with the matrix solution.

Specifically, as shown in Expression (77), the respective components of the matrix S_{MAT} may be calculated

10 with the above integral components S_i (1). That is to say, the integral components S_i (1) are included in the integral component table supplied from the integral component calculation unit 2424, so the normal equation generating unit 2425 can calculate each component of the matrix S_{MAT}

15 using the integral component table.

Also, as shown in Expression (79), the respective components of the matrix P_{MAT} may be calculated with the integral components S_i (1) and the input pixel values P (1). That is to say, the integral components S_i (1) is the same

20 as those included in the respective components of the matrix S_{MAT}, also the input pixel values P (1) are included in the input pixel value table supplied from the input pixel value acquiring unit 2423, so the normal equation generating unit 2425 can calculate each component of the matrix P_{MAT} using

25 the integral component table and input pixel value table.

Thus, the normal equation generating unit 2425 calculates each component of the matrix S_{MAT} and matrix P_{MAT}, and outputs the calculated results (each component of the matrix S_{MAT} and matrix P_{MAT}) to the approximation function

5   generating unit 2426 as a normal equation table.

Upon the normal equation table being output from the normal equation generating unit 2425, in step S2406, the approximation function generating unit 2426 calculates the features w_i (i.e., the coefficients w_i of the approximation

10   function $f(x, y)$ serving as a two-dimensional polynomial) serving as the respective components of the matrix W_{MAT} in the above Expression (80) based on the normal equation table.

Specifically, the normal equation in the above Expression (80) can be transformed as the following

15   Expression (81).

$$W_{MAT} = S_{MAT}^{-1} P_{MAT}$$

...(81)

In Expression (81), the respective components of the matrix W_{MAT} in the left side are the features w_i to be

20   obtained. The respective components regarding the matrix S_{MAT} and matrix P_{MAT} are included in the normal equation table supplied from the normal equation generating unit 2425. Accordingly, the approximation function generating unit 2426 calculates the matrix W_{MAT} by calculating the matrix in the

right side of Expression (81) using the normal equation table, and outputs the calculated results (features w_i) to the image generating unit 103.

In step S2407, the approximation function generating unit 2426 determines regarding whether or not the processing of all the pixels has been completed.

In step S2407, in the event that determination is made that the processing of all the pixels has not been completed, the processing returns to step S2402, wherein the subsequent processing is repeatedly performed. That is to say, the pixels that have not become a pixel of interest are sequentially taken as a pixel of interest, and the processing in step S2402 through S2407 is repeatedly performed.

In the event that the processing of all the pixels has been completed (in step S2407, in the event that determination is made that the processing of all the pixels has been completed), the estimating processing of the actual world 1 ends.

As description of the two-dimensional polynomial approximating method, an example for calculating the coefficients (features) w_i of the approximation function $f(x, y)$ corresponding to the spatial directions (X direction and Y direction) has been employed, but the two-dimensional polynomial approximating method can be applied to the

temporal and spatial directions (X direction and t direction, or Y direction and t direction) as well.

That is to say, the above example is an example in the case of the light signal in the actual world 1 having

5   continuity in the spatial direction represented with the gradient G_F (Fig. 77), and accordingly, the equation including two-dimensional integration in the spatial directions (X direction and Y direction), such as shown in the above Expression (66). However, the concept regarding

10   two-dimensional integration can be applied not only to the spatial direction but also to the temporal and spatial directions (X direction and t direction, or Y direction and t direction).

In other words, with the two-dimensional polynomial

15   approximating method, even in the case in which the light signal function F(x, y, t), which needs to be estimated, has not only continuity in the spatial direction but also continuity in the temporal and spatial directions (however, X direction and t direction, or Y direction and t direction),

20   this can be approximated with a two-dimensional approximation function f.

Specifically, for example, in the event that there is an object moving horizontally in the X direction at uniform velocity, the direction of movement of the object is

25   represented with like a gradient V_F in the X-t plane such as

shown in Fig. 83. In other words, it can be said that the gradient V_F represents the direction of continuity in the temporal and spatial directions in the X-t plane. Accordingly, the data continuity detecting unit 101 can

5   output movement θ such as shown in Fig. 83 (strictly speaking, though not shown in the drawing, movement θ is an angle generated by the direction of data continuity represented with the gradient V_f corresponding to the gradient V_F and the X direction in the spatial direction) as

10   data continuity information corresponding to the gradient V_F representing continuity in the temporal and spatial directions in the X-t plane as well as the above angle θ (data continuity information corresponding to continuity in the spatial directions represented with the gradient G_F in

15   the X-Y plane).

Accordingly, the actual world estimating unit 102 employing the two-dimensional polynomial approximating method can calculate the coefficients (features) w_i of an approximation function $f(x, t)$ in the same method as the

20   above method by employing the movement θ instead of the angle θ. However, in this case, the equation to be employed is not the above Expression (66) but the following Expression (82).

$$P(x, t) = \int_{t-0.5}^{t+0.5} \int_{x-0.5}^{x+0.5} \sum_{i=0}^{n} w_i (x - s \times t)^i dx dt + e$$

... (82)

Note that in Expression (82), s is cot θ (however, θ is movement).

Also, an approximation function f(y, t) focusing

5   attention on the spatial direction Y instead of the spatial direction X can be handled in the same way as the above approximation function f(x, t).

Thus, the two-dimensional polynomial approximating method takes not one-dimensional but two-dimensional

10   integration effects into consideration, so can estimate the light signals in the actual world 1 more accurately than the one-dimensional approximating method.

Next, description will be made regarding the third function approximating method with reference to Fig. 84

15   through Fig. 88.

That is to say, the third function approximating method is a method for estimating the light signal function F(x, y, t) by approximating the light signal function F(x, y, t) with the approximation function f(x, y, t) focusing

20   attention on that the light signal in the actual world 1 having continuity in a predetermined direction of the temporal and spatial directions is represented with the light signal function F(x, y, t), for example. Accordingly, hereafter, the third function approximating method is

25   referred to as a three-dimensional function approximating

method.

Also, with description of the three-dimensional function approximating method, let us say that the sensor 2 is a CCD made up of the multiple detecting elements 2-1

5 disposed on the plane thereof, such as shown in Fig. 84.

With the example in Fig. 84, the direction in parallel with a predetermined side of the detecting elements 2-1 is taken as the X direction serving as one direction of the spatial directions, and the direction orthogonal to the X

10 direction is taken as the Y direction serving as the other direction of the spatial directions. The direction orthogonal to the X-Y plane is taken as the t direction serving as the temporal direction.

Also, with the example in Fig. 84, the spatial shape of

15 the respective detecting elements 2-1 of the sensor 2 is taken as a square of which one side is 1 in length. The shutter time (exposure time) of the sensor 2 is taken as 1.

Further, with the example in Fig. 84, the center of one certain detecting element 2-1 of the sensor 2 is taken as

20 the origin (the position in the X direction is x = 0, and the position in the Y direction is y = 0) in the spatial directions (X direction and Y direction), and also the intermediate point-in-time of the exposure time is taken as the origin (the position in the t direction is t = 0) in the

25 temporal direction (t direction).

In this case, the detecting element 2-1 of which the center is in the origin (x = 0, y = 0) in the spatial directions subjects the light signal function F(x, y, t) to integration with a range of -0.5 through 0.5 in the X

5 direction, with a range of -0.5 through 0.5 in the Y direction, and with a range of -0.5 through 0.5 in the t direction, and outputs the integral value as the pixel value P.

That is to say, the pixel value P output from the

10 detecting element 2-1 of which the center is in the origin in the spatial directions is represented with the following Expression (83).

$$P = \int_{-0.5}^{+0.5} \int_{-0.5}^{+0.5} \int_{-0.5}^{+0.5} F(x, y, t) \, dx \, dy \, dt$$

... (83)

15 Similarly, the other detecting elements 2-1 output the pixel value P shown in Expression (83) by taking the center of the detecting element 2-1 to be processed as the origin in the spatial directions.

Incidentally, as described above, with the three-

20 dimensional function approximating method, the light signal function F(x, y, t) is approximated to the three-dimensional approximation function f(x, y, t).

Specifically, for example, the approximation function f(x, y, t) is taken as a function having N variables

(features), a relational expression between the input pixel values $P(x, y, t)$ corresponding to Expression (83) and the approximation function $f(x, y, t)$ is defined. Thus, in the event that M input pixel values $P(x, y, t)$ more than N are

5   acquired, N variables (features) can be calculated from the defined relational expression. That is to say, the actual world estimating unit 102 can estimate the light signal function $F(x, y, t)$ by acquiring M input pixel values $P(x, y, t)$, and calculating N variables (features).

10   In this case, the actual world estimating unit 102 extracts (acquires) M input images $P(x, y, t)$, of the entire input image by using continuity of data included in an input image (input pixel values) from the sensor 2 as a constraint (i.e., using data continuity information as to an

15   input image to be output from the data continuity detecting unit 101). As a result, the approximation function $f(x, y, t)$ is constrained by continuity of data.

For example, as shown in Fig. 85, in the event that the light signal function $F(x, y, t)$ corresponding to an input

20   image has continuity in the spatial direction represented with the gradient G_F, the data continuity detecting unit 101 results in outputting the angle θ (the angle θ generated between the direction of continuity of data represented with the gradient G_f (not shown) corresponding to the gradient G_F,

25   and the X direction) as data continuity information as to

the input image.

In this case, let us say that a one-dimensional waveform wherein the light signal function F(x, y, t) is projected in the X direction (such a waveform is referred to as an X cross-sectional waveform here) has the same form even in the event of projection in any position in the Y direction.

That is to say, let us say that there is an X cross-sectional waveform having the same form, which is a two-dimensional (spatial directional) waveform continuous in the direction of continuity (angle θ direction as to the X direction), and a three-dimensional waveform wherein such a two-dimensional waveform continues in the temporal direction t, is approximated with the approximation function f(x, y, t).

In other words, an X cross-sectional waveform, which is shifted by a position y in the Y direction from the center of the pixel of interest, becomes a waveform wherein the X cross-sectional waveform passing through the center of the pixel of interest is moved (shifted) by a predetermined amount (amount varies according to the angle θ) in the X direction. Note that hereafter, such an amount is referred to as a shift amount.

This shift amount can be calculated as follows.

That is to say, the gradient V_f (for example, gradient

V_f representing the direction of data continuity corresponding to the gradient V_F in Fig. 85) and angle θ are represented as the following Expression (84).

$$G_f = \tan \theta = \frac{dy}{dx}$$

5   ...(84)

Note that in Expression (84), dx represents the amount of fine movement in the X direction, and dy represents the amount of fine movement in the Y direction as to the dx.

Accordingly, if the shift amount as to the X direction

10   is described as C_x (y), this is represented as the following Expression (85).

$$C_x(y) = \frac{y}{G_f}$$

...(85)

If the shift amount C_x (y) is thus defined, a relational

15   expression between the input pixel values P (x, y, t) corresponding to Expression (83) and the approximation function f (x, y, t) is represented as the following Expression (86).

$$P(x, y, t) = \int_{t_s}^{t_e} \int_{y_s}^{y_e} \int_{x_s}^{x_e} f(x, y, t)\, dxdydt + e$$

20   ...(86)

In Expression (86), e represents a margin of error. t_s represents an integration start position in the t direction,

and t_e represents an integration end position in the t

direction. In the same way, y_s represents an integration

start position in the Y direction, and y_e represents an

integration end position in the Y direction. Also, x_s

5 represents an integration start position in the X direction,

and x_e represents an integration end position in the X

direction. However, the respective specific integral ranges

are as shown in the following Expression (87).

$$t_s = t-0.5$$
$$t_e = t+0.5$$
$$y_s = y-0.5$$
$$y_e = y+0.5$$
$$x_s = x-C_x(y)-0.5$$
$$x_e = x-C_x(y)+0.5$$

10   ...(87)

As shown in Expression (87), it can be represented that

an X cross-sectional waveform having the same form continues

in the direction of continuity (angle θ direction as to the

X direction) by shifting an integral range in the X

15 direction as to a pixel positioned distant from the pixel of

interest by (x, y) in the spatial direction by the shift

amount $C_x(y)$.

Thus, with the three-dimensional approximating method,

the relation between the pixel values P (x, y, t) and the

20 three-dimensional approximation function f (x, y, t) can be

represented with Expression (86) (Expression (87) for the integral range), and accordingly, the light signal function $F(x, y, t)$ (for example, a light signal having continuity in the spatial direction represented with the gradient V_F such

5   as shown in Fig. 85) can be estimated by calculating the N features of the approximation function $f(x, y, t)$, for example, with the least square method using Expression (86) and Expression (87).

Note that in the event that a light signal represented

10   with the light signal function $F(x, y, t)$ has continuity in the spatial direction represented with the gradient V_F such as shown in Fig. 85, the light signal function $F(x, y, t)$ may be approximated as follows.

That is to say, let us say that a one-dimensional

15   waveform wherein the light signal function $F(x, y, t)$ is projected in the Y direction (hereafter, such a waveform is referred to as a Y cross-sectional waveform) has the same form even in the event of projection in any position in the X direction.

20   In other words, let us say that there is a two-dimensional (spatial directional) waveform wherein a Y cross-sectional waveform having the same form continues in the direction of continuity (angle θ direction as to in the X direction), and a three-dimensional waveform wherein such

25   a two-dimensional waveform continues in the temporal

direction t is approximated with the approximation function f(x, y, t).

Accordingly, the Y cross-sectional waveform, which is shifted by x in the X direction from the center of the pixel

5 of interest, becomes a waveform wherein the Y cross-sectional waveform passing through the center of the pixel of interest is moved by a predetermined shift amount (shift amount changing according to the angle θ) in the Y direction.

This shift amount can be calculated as follows.

10 That is to say, the gradient G_F is represented as the above Expression (84), so if the shift amount as to the Y direction is described as $C_y(x)$, this is represented as the following Expression (88).

$$C_y(x) = G_f \times x$$

15   ...(88)

If the shift amount $C_x(y)$ is thus defined, a relational expression between the input pixel values P (x, y, t) corresponding to Expression (83) and the approximation function f(x, y, t) is represented as the above Expression

20 (86), as with when the shift amount $C_x(y)$ is defined.

However, in this case, the respective specific integral ranges are as shown in the following Expression (89).

$$t_s = t - 0.5$$
$$t_e = t + 0.5$$
$$y_s = y - C_y(x) - 0.5$$
$$y_e = y - C_y(x) + 0.5$$
$$x_s = x - 0.5$$
$$x_e = x + 0.5$$

$$\ldots (89)$$

As shown in Expression (89) (and the above Expression (86)), it can be represented that a Y cross-sectional waveform having the same form continues in the direction of continuity (angle θ direction as to the X direction) by shifting an integral range in the Y direction as to a pixel positioned distant from the pixel of interest by (x, y), by the shift amount C_x (y).

Thus, with the three-dimensional approximating method, the integral range of the right side of the above Expression (86) can be set to not only Expression (87) but also Expression (89), and accordingly, the light signal function F(x, y, t) (light signal in the actual world 1 having continuity in the spatial direction represented with the gradient G_F) can be estimated by calculating the n features of the approximation function f(x, y, t) with, for example, the least square method or the like using Expression (86) in which Expression (89) is employed as an integral range.

Thus, Expression (87) and Expression (89), which

represent an integral range, represent essentially the same with only a difference regarding whether perimeter pixels are shifted in the X direction (in the case of Expression (87)) or shifted in the Y direction (in the case of

5   Expression (89)) in response to the direction of continuity.

However, in response to the direction of continuity (gradient G_F), there is a difference regarding whether the light signal function $F(x, y, t)$ is regarded as a group of X cross-sectional waveforms, or is regarded as a group of Y

10 cross-sectional waveforms. That is to say, in the event that the direction of continuity is close to the Y direction, the light signal function $F(x, y, t)$ is preferably regarded as a group of X cross-sectional waveforms. On the other hand, in the event that the direction of continuity is close

15 to the X direction, the light signal function $F(x, y, t)$ is preferably regarded as a group of Y cross-sectional waveforms.

Accordingly, it is preferable that the actual world estimating unit 102 prepares both Expression (87) and

20 Expression (89) as an integral range, and selects any one of Expression (87) and Expression (89) as the integral range of the right side of the appropriate Expression (86) in response to the direction of continuity.

Description has been made regarding the three-

25 dimensional approximation method in the case in which the

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light signal function F(x, y, t) has continuity (for example,
continuity in the spatial direction represented with the
gradient G_F in Fig. 85) in the spatial directions (X
direction and Y direction), but the three-dimensional

5 approximation method can be applied to the case in which the
light signal function F(x, y, t) has continuity (continuity
represented with the gradient V_F) in the temporal and
spatial directions (X direction, Y direction, and t
direction), as shown in Fig. 86.

10 That is to say, in Fig. 86, a light signal function
corresponding to a frame #N - 1 is taken as F (x, y, #N - 1),
a light signal function corresponding to a frame #N is taken
as F (x, y, #N), and a light signal function corresponding
to a frame #N + 1 is taken as F (x, y, #N + 1).

15 Note that in Fig. 86, the horizontal direction is taken
as the X direction serving as one direction of the spatial
directions, the upper right diagonal direction is taken as
the Y direction serving as the other direction of the
spatial directions, and also the vertical direction is taken

20 as the t direction serving as the temporal direction in the
drawing.

Also, the frame #N - 1 is a frame temporally prior to
the frame #N, the frame #N + 1 is a frame temporally
following the frame #N. That is to say, the frame #N - 1,

25 frame #N, and frame #N + 1 are displayed in the sequence of

the frame #N - 1, frame #N, and frame #N + 1.

With the example in Fig. 86, a cross-sectional light level along the direction shown with the gradient V_F (upper right inner direction from lower left near side in the drawing) is regarded as generally constant. Accordingly, with the example in Fig. 86, it can be said that the light signal function $F(x, y, t)$ has continuity in the temporal and spatial directions represented with the gradient V_F.

In this case, in the event that a function $C (x, y, t)$ representing continuity in the temporal and spatial directions is defined, and also the integral range of the above Expression (86) is defined with the defined function $C (x, y, t)$, N features of the approximation function $f(x, y, t)$ can be calculated as with the above Expression (87) and Expression (89).

The function $C (x, y, t)$ is not restricted to a particular function as long as this is a function representing the direction of continuity. However, hereafter, let us say that linear continuity is employed, and $C_x (t)$ and $C_y (t)$ corresponding to the shift amount $C_x (y)$ (Expression (85)) and shift amount $C_y (x)$ (Expression (87)), which are functions representing continuity in the spatial direction described above, are defined as a function $C (x, y, t)$ corresponding thereto as follows.

That is to say, if the gradient as continuity of data

in the temporal and spatial directions corresponding to the gradient G_f representing continuity of data in the above spatial direction is taken as V_f, and if this gradient V_f is divided into the gradient in the X direction (hereafter, referred to as V_{fx}) and the gradient in the Y direction (hereafter, referred to as V_{fy}), the gradient V_{fx} is represented with the following Expression (90), and the gradient V_{fy} is represented with the following Expression (91), respectively.

$$V_{fx} = \frac{dx}{dt}$$

$$...(90)$$

$$V_{fy} = \frac{dy}{dt}$$

$$...(91)$$

In this case, the function $C_x(t)$ is represented as the following Expression (92) using the gradient V_{fx} shown in Expression (90).

$$C_x(t) = V_{fx} \times t$$

$$...(92)$$

Similarly, the function $C_y(t)$ is represented as the following Expression (93) using the gradient V_{fy} shown in Expression (91).

$$C_y(t) = V_{fy} \times t$$

$$...(93)$$

Thus, upon the function C_x (t) and function C_y (t), which represent continuity 2511 in the temporal and spatial directions, being defined, the integral range of Expression (86) is represented as the following Expression (94).

$$t_s = t-0.5$$
$$t_e = t+0.5$$
$$y_s = y-C_y(t)-0.5$$
$$y_e = y-C_y(t)+0.5$$
$$x_s = x-C_x(t)-0.5$$
$$x_e = x-C_x(t)+0.5$$

$$\ldots (94)$$

Thus, with the three-dimensional approximating method, the relation between the pixel values P (x, y, t) and the three-dimensional approximation function f (x, y, t) can be represented with Expression (86), and accordingly, the light signal function F(x, y, t) (light signal in the actual world 1 having continuity in a predetermined direction of the temporal and spatial directions) can be estimated by calculating the n + 1 features of the approximation function f (x, y, t) with, for example, the least square method or the like using Expression (94) as the integral range of the right side of Expression (86).

Fig. 87 represents a configuration example of the actual world estimating unit 102 employing such a three-dimensional approximating method.

Note that the approximation function f(x, y, t) (in reality, the features (coefficients) thereof) calculated by the actual world estimating unit 102 employing the three-dimensional approximating method is not restricted to a
5   particular function, but an n (n = N - 1) -dimensional polynomial is employed in the following description.

As shown in Fig. 87, the actual world estimating unit 102 includes a conditions setting unit 2521, input image storage unit 2522, input pixel value acquiring unit 2523,
10   integral component calculation unit 2524, normal equation generating unit 2525, and approximation function generating unit 2526.

The conditions setting unit 2521 sets a pixel range (tap range) used for estimating the light signal function
15   F(x, y, t) corresponding to a pixel of interest, and the number of dimensions n of the approximation function f(x, y, t).

The input image storage unit 2522 temporarily stores an input image (pixel values) from the sensor 2.
20   The input pixel acquiring unit 2523 acquires, of the input images stored in the input image storage unit 2522, an input image region corresponding to the tap range set by the conditions setting unit 2521, and supplies this to the normal equation generating unit 2525 as an input pixel value
25   table. That is to say, the input pixel value table is a

table in which the respective pixel values of pixels included in the input image region are described.

Incidentally, as described above, the actual world estimating unit 102 employing the three-dimensional approximating method calculates the N features (in this case, coefficient of each dimension) of the approximation function f(x, y, t) with the least square method using the above Expression (86) (however, Expression (87), Expression (90), or Expression (94) for the integral range).

The right side of Expression (86) can be represented as the following Expression (95) by calculating the integration thereof.

$$P(x, y, t) = \sum_{i=0}^{n} w_i S_i (x_s, x_e, y_s, y_e, t_s, t_e) + e$$

$$\ldots (95)$$

In Expression (95), w_i represents the coefficients (features) of the i-dimensional term, and also S_i (x_s, x_e, y_s, y_e, t_s, t_e) represents the integral components of the i-dimensional term. However, x_s represents an integral range start position in the X direction, x_e represents an integral range end position in the X direction, y_s represents an integral range start position in the Y direction, y_e represents an integral range end position in the Y direction, t_s represents an integral range start position in the t direction, t_e represents an integral range end position in

the t direction, respectively.

The integral component calculation unit 2524 calculates the integral components S_i (x_s, x_e, y_s, y_e, t_s, t_e).

That is to say, the integral component calculation unit

5   2524 calculates the integral components S_i (x_s, x_e, y_s, y_e, t_s, t_e) based on the tap range and the number of dimensions set by the conditions setting unit 2521, and the angle or movement (as the integral range, angle in the case of using the above Expression (87) or Expression (90), and movement

10   in the case of using the above Expression (94)) of the data continuity information output from the data continuity detecting unit 101, and supplies the calculated results to the normal equation generating unit 2525 as an integral component table.

15   The normal equation generating unit 2525 generates a normal equation in the case of obtaining the above Expression (95) with the least square method using the input pixel value table supplied from the input pixel value acquiring unit 2523, and the integral component table

20   supplied from the integral component calculation unit 2524, and outputs this to the approximation function generating unit 2526 as a normal equation table. An example of a normal equation will be described later.

The approximation function generating unit 2526

25   calculates the respective features w_i (in this case, the

coefficients w_i of the approximation function $f(x, y, t)$

serving as a three-dimensional polynomial) by solving the

normal equation included in the normal equation table

supplied from the normal equation generating unit 2525 with

5   the matrix solution, and output these to the image

generating unit 103.

Next, description will be made regarding the actual

world estimating processing (processing in step S102 in Fig.

29) to which the three-dimensional approximating method is

10   applied, with reference to the flowchart in Fig. 88.

First, in step S2501, the conditions setting unit 2521

sets conditions (a tap range and the number of dimensions).

For example, let us say that a tap range made up of L

pixels has been set. Also, let us say that a predetermined

15   number l (l is any one of integer values 0 through L - 1) is

appended to each of the pixels.

Next, in step S2502, the conditions setting unit 2521

sets a pixel of interest.

In step S2503, the input pixel value acquiring unit

20   2523 acquires an input pixel value based on the condition

(tap range) set by the conditions setting unit 2521, and

generates an input pixel value table. In this case, a table

made up of L input pixel values $P(x, y, t)$ is generated.

Here, let us say that each of the L input pixel values $P(x,

25   y, t)$ is described as $P(l)$ serving as a function of the

number l of the pixel thereof. That is to say, the input

pixel value table becomes a table including L P (l).

In step S2504, the integral component calculation unit

2524 calculates integral components based on the conditions

5 (a tap range and the number of dimensions) set by the

conditions setting unit 2521, and the data continuity

information (angle or movement) supplied from the data

continuity detecting unit 101, and generates an integral

component table.

10 However, in this case, as described above, the input

pixel values are not P (x, y, t) but P (l), and are acquired

as the value of a pixel number l, so the integral component

calculation unit 2524 results in calculating the integral

components S_i (x_s, x_e, y_s, y_e, t_s, t_e) in the above Expression

15 (95) as a function of l such as the integral components S_i

(l). That is to say, the integral component table becomes a

table including L × i S_i (l).

Note that the sequence of the processing in step S2503

and the processing in step S2504 is not restricted to the

20 example in Fig. 88, so the processing in step S2504 may be

executed first, or the processing in step S2503 and the

processing in step S2504 may be executed simultaneously.

Next, in step S2505, the normal equation generating

unit 2525 generates a normal equation table based on the

25 input pixel value table generated by the input pixel value

acquiring unit 2523 at the processing in step S2503, and the integral component table generated by the integral component calculation unit 2524 at the processing in step S2504.

Specifically, in this case, the features w_i of the following Expression (96) corresponding to the above Expression (95) are calculated using the least square method. A normal equation corresponding to this is represented as the following Expression (97).

$$P(I) = \sum_{i=0}^{n} w_i S_i(I) + e$$

$$\dots (96)$$

$$
\begin{pmatrix}
\sum_{I=0}^{L} S_0(I)S_0(I) & \sum_{I=0}^{L} S_0(I)S_1(I) & \cdots & \sum_{I=0}^{L} S_0(I)S_n(I) \\
\sum_{I=0}^{L} S_1(I)S_0(I) & \sum_{I=0}^{L} S_1(I)S_1(I) & \cdots & \sum_{I=0}^{L} S_1(I)S_n(I) \\
\vdots & \vdots & \ddots & \vdots \\
\sum_{I=0}^{L} S_n(I)S_0(I) & \sum_{I=0}^{L} S_n(I)S_1(I) & \cdots & \sum_{I=0}^{L} S_n(I)S_n(I)
\end{pmatrix}
\begin{pmatrix}
w_0 \\
w_1 \\
\vdots \\
w_n
\end{pmatrix}
=
\begin{pmatrix}
\sum_{I=0}^{L} S_0(I)P(I) \\
\sum_{I=0}^{L} S_1(I)P(I) \\
\vdots \\
\sum_{I=0}^{L} S_n(I)P(I)
\end{pmatrix}
$$

$$\dots (97)$$

If we define each matrix of the normal equation shown in Expression (97) as the following Expressions (98) through (100), the normal equation is represented as the following Expression (101).

).

$$S_{MAT} = \begin{pmatrix} \sum_{l=0}^{L} S_0(l)S_0(l) & \sum_{l=0}^{L} S_0(l)S_1(l) & \cdots & \sum_{l=0}^{L} S_0(l)S_n(l) \\ \sum_{l=0}^{L} S_1(l)S_0(l) & \sum_{l=0}^{L} S_1(l)S_1(l) & \cdots & \sum_{l=0}^{L} S_1(l)S_n(l) \\ \vdots & \vdots & \ddots & \vdots \\ \sum_{l=0}^{L} S_n(l)S_0(l) & \sum_{l=0}^{L} S_n(l)S_1(l) & \cdots & \sum_{l=0}^{L} S_n(l)S_n(l) \end{pmatrix}$$

$$\ldots (98)$$

$$W_{MAT} = \begin{pmatrix} w_0 \\ w_1 \\ \vdots \\ w_n \end{pmatrix}$$

$$\ldots (99)$$

$$P_{MAT} = \begin{pmatrix} \sum_{l=0}^{L} S_0(l)P(l) \\ \sum_{l=0}^{L} S_1(l)P(l) \\ \vdots \\ \sum_{l=0}^{L} S_n(l)P(l) \end{pmatrix}$$

5

$$\ldots (100)$$

$$S_{MAT} W_{MAT} = P_{MAT}$$

S04P0850

$$\ldots(101)$$

As shown in Expression (99), the respective components of the matrix W_{MAT} are the features w_i to be obtained. Accordingly, in Expression (101), if the matrix S_{MAT} of the left side and the matrix P_{MAT} of the right side are determined, the matrix W_{MAT} (i.e., features w_i) may be calculated with the matrix solution.

Specifically, as shown in Expression (98), the respective components of the matrix S_{MAT} may be calculated as long as the above integral components S_i (l) are known. The integral components S_i (l) are included in the integral component table supplied from the integral component calculation unit 2524, so the normal equation generating unit 2525 can calculate each component of the matrix S_{MAT} using the integral component table.

Also, as shown in Expression (100), the respective components of the matrix P_{MAT} may be calculated as long as the integral components S_i (l) and the input pixel values P (l) are known. The integral components S_i (l) is the same as those included in the respective components of the matrix S_{MAT}, also the input pixel values P (l) are included in the input pixel value table supplied from the input pixel value acquiring unit 2523, so the normal equation generating unit 2525 can calculate each component of the matrix P_{MAT} using the integral component table and input pixel value table.

Thus, the normal equation generating unit 2525 calculates each component of the matrix S_{MAT} and matrix P_{MAT}, and outputs the calculated results (each component of the matrix S_{MAT} and matrix P_{MAT}) to the approximation function

5   generating unit 2526 as a normal equation table.

Upon the normal equation table being output from the normal equation generating unit 2526, in step S2506, the approximation function generating unit 2526 calculates the features w_i (i.e., the coefficients w_i of the approximation

10   function $f(x, y, t)$) serving as the respective components of the matrix W_{MAT} in the above Expression (101) based on the normal equation table.

Specifically, the normal equation in the above Expression (101) can be transformed as the following

15   Expression (102).

$$W_{MAT} = S_{MAT}^{-1} P_{MAT}$$

...(102)

In Expression (102), the respective components of the matrix W_{MAT} in the left side are the features w_i to be

20   obtained. The respective components regarding the matrix S_{MAT} and matrix P_{MAT} are included in the normal equation table supplied from the normal equation generating unit 2525. Accordingly, the approximation function generating unit 2526 calculates the matrix W_{MAT} by calculating the matrix in the

right side of Expression (102) using the normal equation
table, and outputs the calculated results (features w_i) to
the image generating unit 103.

In step S2507, the approximation function generating
unit 2526 determines regarding whether or not the processing
of all the pixels has been completed.

In step S2507, in the event that determination is made
that the processing of all the pixels has not been completed,
the processing returns to step S2502, wherein the subsequent
processing is repeatedly performed. That is to say, the
pixels that have not become a pixel of interest are
sequentially taken as a pixel of interest, and the
processing in step S2502 through S2507 is repeatedly
performed.

In the event that the processing of all the pixels has
been completed (in step S2507, in the event that
determination is made that the processing of all the pixels
has been completed), the estimating processing of the actual
world 1 ends.

As described above, the three-dimensional approximating
method takes three-dimensional integration effects in the
temporal and spatial directions into consideration instead
of one-dimensional or two-dimensional integration effects,
and accordingly, can estimate the light signals in the
actual world 1 more accurately than the one-dimensional

approximating method and two-dimensional polynomial

approximating method.

Next, description will be made regarding an embodiment

of the image generating unit 103 (Fig. 3) with reference to

5   Fig. 89 through Fig. 110.

Fig. 89 is a diagram for describing the principle of

the present embodiment.

As shown in Fig. 89, the present embodiment is based on

condition that the actual world estimating unit 102 employs

10   a function approximating method. That is to say, let us say

that the signals in the actual world 1 (distribution of

light intensity) serving as an image cast in the sensor 2

are represented with a predetermined function F, it is an

assumption for the actual world estimating unit 102 to

15   estimate the function F by approximating the function F with

a predetermined function f using the input image (pixel

value P) output from the sensor 2 and the data continuity

information output from the data continuity detecting unit

101.

20   Note that hereafter, with description of the present

embodiment, the signals in the actual world 1 serving as an

image are particularly referred to as light signals, and the

function F is particularly referred to as a light signal

function F. Also, the function f is particularly referred

25   to as an approximation function f.

With the present embodiment, the image generating unit 103 integrates the approximation function f with a predetermined time-space range using the data continuity information output from the data continuity detecting unit 101, and the actual world estimating information (in the example in Fig. 89, the features of the approximation function f or approximation function f of which the features are identified) output from the actual world estimating unit 102 based on such an assumption, and outputs the integral value as an output pixel value M (output image). Note that with the present embodiment, an input pixel value is described as P, and an output pixel value is described as M in order to distinguish an input image pixel from an output image pixel.

In other words, upon the light signal function F being integrated once, the light signal function F becomes an input pixel value P, the light signal function F is estimated from the input pixel value P (approximated with the approximation function f), the estimated light signal function F(i.e., approximation function f) is integrated again, and an output pixel value M is generated. Accordingly, hereafter, integration of the approximation function f executed by the image generating unit 103 is referred to as reintegration. Also, the present embodiment is referred to as a reintegration method.

Note that as described later, with the reintegration method, the integral range of the approximation function f in the event that the output pixel value M is generated is not restricted to the integral range of the light signal function F in the event that the input pixel value P is generated (i.e., the vertical width and horizontal width of the detecting element of the sensor 2 for the spatial direction, the exposure time of the sensor 2 for the temporal direction), an arbitrary integral range may be employed.

For example, in the event that the output pixel value M is generated, varying the integral range in the spatial direction of the integral range of the approximation function f enables the pixel pitch of an output image according to the integral range thereof to be varied. That is to say, creation of spatial resolution is available.

In the same way, for example, in the event that the output pixel value M is generated, varying the integral range in the temporal direction of the integral range of the approximation function f enables creation of temporal resolution.

Hereafter, description will be made individually regarding three specific methods of such a reintegration method with reference to the drawings.

That is to say, three specific methods are

reintegration methods corresponding to three specific methods of the function approximating method (the above three specific examples of the embodiment of the actual world estimating unit 102) respectively.

5　　　Specifically, the first method is a reintegration method corresponding to the above one-dimensional approximating method (one method of the function approximating method). Accordingly, with the first method, one-dimensional reintegration is performed, so hereafter,

10　such a reintegration method is referred to as a one-dimensional reintegration method.

The second method is a reintegration method corresponding to the above two-dimensional polynomial approximating method (one method of the function

15　approximating method). Accordingly, with the second method, two-dimensional reintegration is performed, so hereafter, such a reintegration method is referred to as a two-dimensional reintegration method.

The third method is a reintegration method

20　corresponding to the above three-dimensional approximating method (one method of the function approximating method). Accordingly, with the third method, three-dimensional reintegration is performed, so hereafter, such a reintegration method is referred to as a three-dimensional

25　reintegration method.

Hereafter, description will be made regarding each
details of the one-dimensional reintegration method, two-
dimensional reintegration method, and three-dimensional
reintegration method in this order.

5   First, the one-dimensional reintegration method will be
described.

With the one-dimensional reintegration method, it is
assumed that the approximation function f(x) is generated
using the one-dimensional approximating method.

10   That is to say, it is an assumption that a one-
dimensional waveform (with description of the reintegration
method, a waveform projected in the X direction of such a
waveform is referred to as an X cross-sectional waveform
F(x)) wherein the light signal function F(x, y, t) of which

15   variables are positions x, y, and z on the three-dimensional
space, and a point-in-time t is projected in a predetermined
direction (for example, X direction) of the X direction, Y
direction, and Z direction serving as the spatial direction,
and t direction serving as the temporal direction, is

20   approximated with the approximation function f(x) serving as
an n-dimensional (n is an arbitrary integer) polynomial.

In this case, with the one-dimensional reintegration
method, the output pixel value M is calculated such as the
following Expression (103).

$$M = G_e \times \int_{x_s}^{x_e} f(x)\,dx$$

... (103)

Note that in Expression (103), x_s represents an integration start position, x_e represents an integration end

5　position. Also, G_e represents a predetermined gain.

Specifically, for example, let us say that the actual world estimating unit 102 has already generated the approximation function $f(x)$ (the approximation function $f(x)$ of the X cross-sectional waveform $F(x)$) such as shown in Fig.

10　90 with a pixel 3101 (pixel 3101 corresponding to a predetermined detecting element of the sensor 2) such as shown in Fig. 90 as a pixel of interest.

Note that with the example in Fig. 90, the pixel value (input pixel value) of the pixel 3101 is taken as P, and the

15　shape of the pixel 3101 is taken as a square of which one side is 1 in length. Also, of the spatial directions, the direction in parallel with one side of the pixel 3101 (horizontal direction in the drawing) is taken as the X direction, and the direction orthogonal to the X direction

20　(vertical direction in the drawing) is taken as the Y direction.

Also, on the lower side in Fig. 90, the coordinates system (hereafter, referred to as a pixel-of-interest coordinates system) in the spatial directions (X direction

and Y direction) of which the center of the pixel 3101 is taken as the origin, and the pixel 3101 in the coordinates system are shown.

Further, on the upward direction in Fig. 90, a graph
5   representing the approximation function f(x) at y = 0 (y is a coordinate value in the Y direction in the pixel-of-interest coordinates system shown on the lower side in the drawing) is shown. In this graph, the axis in parallel with the horizontal direction in the drawing is the same axis as
10   the x axis in the X direction in the pixel-of-interest coordinates system shown on the lower side in the drawing (the origin is also the same), and also the axis in parallel with the vertical direction in the drawing is taken as an axis representing pixel values.

15   In this case, the relation of the following Expression (104) holds between the approximation function f(x) and the pixel value P of the pixel 3101.

$$P = \int_{-0.5}^{0.5} f(x)\,dx + e$$

...(104)

20   Also, as shown in Fig. 90, let us say that the pixel 3101 has continuity of data in the spatial direction represented with the gradient G_f. Further, let us say that the data continuity detecting unit 101 (Fig. 89) has already output the angle θ such as shown in Fig. 90 as data

continuity information corresponding to continuity of data represented with the gradient G_f.

In this case, for example, with the one-dimensional reintegration method, as shown in Fig. 91, four pixels 3111

5   through 3114 can be newly created in a range of -0.5 through 0.5 in the X direction, and also in a range of -0.5 through 0.5 in the Y direction (in the range where the pixel 3101 in Fig. 90 is positioned).

Note that on the lower side in Fig. 91, the same pixel-

10 of-interest coordinates system as that in Fig. 90, and the pixels 3111 through 3114 in the pixel-of-interest coordinates system thereof are shown. Also, on the upper side in Fig. 91, the same graph (graph representing the approximation function f(x) at y = 0) as that in Fig. 90 is

15 shown.

Specifically, as shown in Fig. 91, with the one-dimensional reintegration method, calculation of the pixel value M (1) of the pixel 3111 using the following Expression (105), calculation of the pixel value M (2) of the pixel

20 3112 using the following Expression (106), calculation of the pixel value M (3) of the pixel 3113 using the following Expression (107), and calculation of the pixel value M (4) of the pixel 3114 using the following Expression (108) are available respectively.

$$M(1) = 2 \times \int_{x_{s1}}^{x_{e1}} f(x)\, dx$$

...(105)

$$M(2) = 2 \times \int_{x_{s2}}^{x_{e2}} f(x)\, dx$$

...(106)

$$M(3) = 2 \times \int_{x_{s3}}^{x_{e3}} f(x)\, dx$$

...(107)

$$M(4) = 2 \times \int_{x_{s4}}^{x_{e4}} f(x)\, dx$$

...(108)

Note that x_{s1} in Expression (105), x_{s2} in Expression (106), x_{s3} in Expression (107), and x_{s4} in Expression (108) each represent the integration start position of the corresponding expression. Also, x_{e1} in Expression (105), x_{e2} in Expression (106), x_{e3} in Expression (107), and x_{e4} in Expression (108) each represent the integration end position of the corresponding expression.

The integral range in the right side of each of Expression (105) through Expression (108) becomes the pixel width (length in the X direction) of each of the pixel 3111 through pixel 3114. That is to say, each of $x_{e1} - x_{s1}$, $x_{e2} - x_{s2}$, $x_{e3} - x_{s3}$, and $x_{e4} - x_{s4}$ becomes 0.5.

However, in this case, it can be conceived that a one-

dimensional waveform having the same form as that in the

approximation function f(x) at y = 0 continues not in the Y

direction but in the direction of data continuity

represented with the gradient G_f (i.e., angle θ direction)

5   (in fact, a waveform having the same form as the X cross-

sectional waveform F(x) at y = 0 continues in the direction

of continuity). That is to say, in the case in which a

pixel value f (0) in the origin (0, 0) in the pixel-of-

interest coordinates system in Fig. 91 (center of the pixel

10   3101 in Fig. 90) is taken as a pixel value f1, the direction

where the pixel value f1 continues is not the Y direction

but the direction of data continuity represented with the

gradient G_f (angle θ direction).

In other words, in the case of conceiving the waveform

15   of the approximation function f(x) in a predetermined

position y in the Y direction (however, y is a numeric value

other than zero), the position corresponding to the pixel

value f1 is not a position (0, y) but a position (C_x (y), y)

obtained by moving in the X direction from the position (0,

20   y) by a predetermined amount (here, let us say that such an

amount is also referred to as a shift amount. Also, a shift

amount is an amount depending on the position y in the Y

direction, so let us say that this shift amount is described

as C_x (y)).

25   Accordingly, as the integral range of the right side of

each of the above Expression (105) through Expression (108),

the integral range needs to be set in light of the position

y in the Y direction where the center of the pixel value M

(1) to be obtained (however, 1 is any integer value of 1

5   through 4) exists, i.e., the shift amount C_x (y).

Specifically, for example, the position y in the Y

direction where the centers of the pixel 3111 and pixel 3112

exist is not y = 0 but y = 0.25.

Accordingly, the waveform of the approximation function

10   f(x) at y = 0.25 is equivalent to a waveform obtained by

moving the waveform of the approximation function f(x) at y

= 0 by the shift amount C_x (0.25) in the X direction.

In other words, in the above Expression (105), if we

say that the pixel value M (1) as to the pixel 3111 is

15   obtained by integrating the approximation function f(x) at y

= 0 with a predetermined integral range (from the start

position x_{s1} to the end position x_{e1}), the integral range

thereof becomes not a range from the start position x_{s1} = -

0.5 to the end position x_{e1} = 0 (a range itself where the

20   pixel 3111 occupies in the X direction) but the range shown

in Fig. 91, i.e., from the start position x_{s1} = -0.5 + C_x

(0.25) to the end position x_{e1} = 0 + C_x (0.25) (a range where

the pixel 3111 occupies in the X direction in the event that

the pixel 3111 is tentatively moved by the shift amount C_x

25   (0.25)).

Similarly, in the above Expression (106), if we say that the pixel value M (2) as to the pixel 3112 is obtained by integrating the approximation function f(x) at y = 0 with a predetermined integral range (from the start position x_{s2}

5   to the end position x_{e2}), the integral range thereof becomes not a range from the start position x_{s2} = 0 to the end position x_{e2} = 0.5 (a range itself where the pixel 3112 occupies in the X direction) but the range shown in Fig. 91, i.e., from the start position x_{s2} = 0 + C_x (0.25) to the end

10   position x_{e1} = 0.5 + C_x (0.25) (a range where the pixel 3112 occupies in the X direction in the event that the pixel 3112 is tentatively moved by the shift amount C_x (0.25)).

Also, for example, the position y in the Y direction where the centers of the pixel 3113 and pixel 3114 exist is

15   not y = 0 but y = -0.25.

Accordingly, the waveform of the approximation function f(x) at y = -0.25 is equivalent to a waveform obtained by moving the waveform of the approximation function f(x) at y = 0 by the shift amount C_x (-0.25) in the X direction.

20   In other words, in the above Expression (107), if we say that the pixel value M (3) as to the pixel 3113 is obtained by integrating the approximation function f(x) at y = 0 with a predetermined integral range (from the start position x_{s3} to the end position x_{e3}), the integral range

25   thereof becomes not a range from the start position x_{s3} = -

0.5 to the end position x_{e3} = 0 (a range itself where the

pixel 3113 occupies in the X direction) but the range shown

in Fig. 91, i.e., from the start position x_{s3} = -0.5 + C_x (-

0.25) to the end position x_{e3} = 0 + C_x (-0.25) (a range where

5   the pixel 3113 occupies in the X direction in the event that

the pixel 3113 is tentatively moved by the shift amount C_x

(-0.25)).

Similarly, in the above Expression (108), if we say

that the pixel value M (4) as to the pixel 3114 is obtained

10   by integrating the approximation function f(x) at y = 0 with

a predetermined integral range (from the start position x_{s4}

to the end position x_{e4}), the integral range thereof becomes

not a range from the start position x_{s4} = 0 to the end

position x_{e4} = 0.5 (a range itself where the pixel 3114

15   occupies in the X direction) but the range shown in Fig. 91,

i.e., from the start position x_{s4} = 0 + C_x (-0.25) to the end

position x_{e1} = 0.5 + C_x (-0.25) (a range where the pixel 3114

occupies in the X direction in the event that the pixel 3114

is tentatively moved by the shift amount C_x (-0.25)).

20   Accordingly, the image generating unit 102 (Fig. 89)

calculates the above Expression (105) through Expression

(108) by substituting the corresponding integral range of

the above integral ranges for each of these expressions, and

outputs the calculated results of these as the output pixel

25   values M (1) through M (4).

Thus, the image generating unit 102 can create four pixels having higher spatial resolution than that of the output pixel 3101, i.e., the pixel 3111 through pixel 3114 (Fig. 91) by employing the one-dimensional reintegration

5 method as a pixel at the output pixel 3101 (Fig. 90) from the sensor 2 (Fig. 89). Further, though not shown in the drawing, as described above, the image generating unit 102 can create a pixel having an arbitrary powered spatial resolution as to the output pixel 3101 without deterioration

10 by appropriately changing an integral range, in addition to the pixel 3111 through pixel 3114.

Fig. 92 represents a configuration example of the image generating unit 103 employing such a one-dimensional reintegration method.

15 As shown in Fig. 92, the image generating unit 103 shown in this example includes a conditions setting unit 3121, features storage unit 3122, integral component calculation unit 3123, and output pixel value calculation unit 3124.

20 The conditions setting unit 3121 sets the number of dimensions n of the approximation function f(x) based on the actual world estimating information (the features of the approximation function f(x) in the example in Fig. 92) supplied from the actual world estimating unit 102.

25 The conditions setting unit 3121 also sets an integral

range in the case of reintegrating the approximation

function f(x) (in the case of calculating an output pixel

value). Note that an integral range set by the conditions

setting unit 3121 does not need to be the width of a pixel.

5   For example, the approximation function f(x) is integrated

in the spatial direction (X direction), and accordingly, a

specific integral range can be determined as long as the

relative size (power of spatial resolution) of an output

pixel (pixel to be calculated by the image generating unit

10   103) as to the spatial size of each pixel of an input image

from the sensor 2 (Fig. 89) is known. Accordingly, the

conditions setting unit 3121 can set, for example, a spatial

resolution power as an integral range.

The features storage unit 3122 temporally stores the

15   features of the approximation function f(x) sequentially

supplied from the actual world estimating unit 102.

Subsequently, upon the features storage unit 3122 storing

all of the features of the approximation function f(x), the

features storage unit 3122 generates a features table

20   including all of the features of the approximation function

f(x), and supplies this to the output pixel value

calculation unit 3124.

Incidentally, as described above, the image generating

unit 103 calculates the output pixel value M using the above

25   Expression (103), but the approximation function f(x)

included in the right side of the above Expression (103) is represented as the following Expression (109) specifically.

$$f(x) = \sum_{i=0}^{n} w_i \times x^i \, dx$$

$$\ldots (109)$$

5   Note that in Expression (109), w_i represents the features of the approximation function $f(x)$ supplied from the actual world estimating unit 102.

Accordingly, upon the approximation function $f(x)$ of Expression (109) being substituted for the approximation

10   function $f(x)$ of the right side of the above Expression (103) so as to expand (calculate) the right side of Expression (103), the output pixel value M is represented as the following Expression (110).

$$M = G_e \times \sum_{i=0}^{n} w_i \times \frac{x_e^{i+1} - x_s^{i+1}}{i+1}$$

$$= \sum_{i=0}^{n} w_i \times k_i (x_s, x_e)$$

15

$$\ldots (110)$$

In Expression (110), $K_i (x_s, x_e)$ represent the integral components of the i-dimensional term. That is to say, the integral components $K_i (x_s, x_e)$ are such as shown in the following Expression (111).

$$k_i (x_s, x_e) = G_e \times \frac{x_e^{i+1} - x_s^{i+1}}{i+1}$$

20

... (111)

The integral component calculation unit 3123 calculates the integral components K_i (x_s, x_e).

Specifically, as shown in Expression (111), the integral components K_i (x_s, x_e) can be calculated as long as the start position x_s and end position x_e of an integral range, gain G_e, and i of the i-dimensional term are known.

Of these, the gain G_e is determined with the spatial resolution power (integral range) set by the conditions setting unit 3121.

The range of i is determined with the number of dimensions n set by the conditions setting unit 3121.

Also, each of the start position x_s and end position x_e of an integral range is determined with the center pixel position (x, y) and pixel width of an output pixel to be generated from now, and the shift amount C_x (y) representing the direction of data continuity. Note that (x, y) represents the relative position from the center position of a pixel of interest when the actual world estimating unit 102 generates the approximation function f(x).

Further, each of the center pixel position (x, y) and pixel width of an output pixel to be generated from now is determined with the spatial resolution power (integral range) set by the conditions setting unit 3121.

Also, with the shift amount C_x (y), and the angle θ

supplied from the data continuity detecting unit 101, the
relation such as the following Expression (112) and
Expression (113) holds, and accordingly, the shift amount C_x
(y) is determined with the angle θ.

$$G_f = \tan \theta = \frac{dy}{dx}$$

5

$$\qquad \qquad \qquad \qquad \qquad \qquad \qquad \ldots (112)$$

$$C_x(y) = \frac{y}{G_f}$$

$$\qquad \qquad \qquad \qquad \qquad \qquad \qquad \ldots (113)$$

Note that in Expression (112), G_f represents a gradient
10   representing the direction of data continuity, θ represents
an angle (angle generated between the X direction serving as
one direction of the spatial directions and the direction of
data continuity represented with a gradient G_f) of one of
the data continuity information output from the data
15   continuity detecting unit 101 (Fig. 89). Also, dx
represents the amount of fine movement in the X direction,
and dy represents the amount of fine movement in the Y
direction (spatial direction perpendicular to the X
direction) as to the dx.

20   Accordingly, the integral component calculation unit
3123 calculates the integral components K_i (x_s, x_e) based on
the number of dimensions and spatial resolution power
(integral range) set by the conditions setting unit 3121,

and the angle θ of the data continuity information output from the data continuity detecting unit 101, and supplies the calculated results to the output pixel value calculation unit 3124 as an integral component table.

5   The output pixel value calculation unit 3124 calculates the right side of the above Expression (110) using the features table supplied from the features storage unit 3122 and the integral component table supplied from the integral component calculation unit 3123, and outputs the calculation

10   result as an output pixel value M.

Next, description will be made regarding image generating processing (processing in step S103 in Fig. 29) by the image generating unit 103 (Fig. 92) employing the one-dimensional reintegration method with reference to the

15   flowchart in Fig. 93.

For example, now, let us say that the actual world estimating unit 102 has already generated the approximation function f(x) such as shown in Fig. 90 while taking the pixel 3101 such as shown in Fig. 90 described above as a

20   pixel of interest at the processing in step S102 in Fig. 29 described above.

Also, let us say that the data continuity detecting unit 101 has already output the angle θ such as shown in Fig. 90 as data continuity information at the processing in step

25   S101 in Fig. 29 described above.

In this case, the conditions setting unit 3121 sets conditions (the number of dimensions and an integral range) at step S3101 in Fig. 93.

For example, now, let us say that 5 has been set as the number of dimensions, and also a spatial quadruple density (spatial resolution power to cause the pitch width of a pixel to become half power in the upper/lower/left/right sides) has been set as an integral range.

That is to say, in this case, consequently, it has been set that the four pixel 3111 through pixel 3114 are created newly in a range of -0.5 through 0.5 in the X direction, and also a range of -0.5 through 0.5 in the Y direction (in the range of the pixel 3101 in Fig. 90), such as shown in Fig. 91.

In step S3102, the features storage unit 3122 acquires the features of the approximation function f(x) supplied from the actual world estimating unit 102, and generates a features table. In this case, coefficients w_0 through w_5 of the approximation function f(x) serving as a five-dimensional polynomial are supplied from the actual world estimating unit 102, and accordingly, $(w_0, w_1, w_2, w_3, w_4, w_5)$ is generated as a features table.

In step S3103, the integral component calculation unit 3123 calculates integral components based on the conditions (the number of dimensions and integral range) set by the

conditions setting unit 3121, and the data continuity

information (angle θ) supplied from the data continuity

detecting unit 101, and generates an integral component

table.

5   Specifically, for example, if we say that the

respective pixels 3111 through 3114, which are to be

generated from now, are appended with numbers (hereafter,

such a number is referred to as a mode number) 1 through 4,

the integral component calculation unit 3123 calculates the

10   integral components K_i (x_s, x_e) of the above Expression (111)

as a function of 1 (however, 1 represents a mode number)

such as integral components K_i (1) shown in the left side of

the following Expression (114).

K_i (1) = K_i (x_s, x_e)

15   ...(114)

     Specifically, in this case, the integral components K_i

(1) shown in the following Expression (115) are calculated.

$$k_i(1) = k_i(-0.5-C_x(-0.25), 0-C_x(-0.25))$$
$$k_i(2) = k_i(0-C_x(-0.25), 0.5-C_x(-0.25))$$
$$k_i(3) = k_i(-0.5-C_x(0.25), 0-C_x(0.25))$$
$$k_i(4) = k_i(0-C_x(0.25), 0.5-C_x(0.25))$$

                                                    ...(115)

20   Note that in Expression (115), the left side represents

the integral components K_i (1), and the right side

represents the integral components K_i (x_s, x_e). That is to

say, in this case, l is any one of 1 through 4, and also i

is any one of 0 through 5, and accordingly, 24 K_i (l) in

total of 6 K_i (1), 6 K_i (2), 6 K_i (3), and 6 K_i (4) are

calculated.

5   More specifically, first, the integral component

calculation unit 3123 calculates each of the shift amounts

C_x (-0.25) and C_x (0.25) from the above Expression (112) and

Expression (113) using the angle θ supplied from the data

continuity detecting unit 101.

10   Next, the integral component calculation unit 3123

calculates the integral components K_i (x_s, x_e) of each right

side of the four expressions in Expression (115) regarding i

= 0 through 5 using the calculated shift amounts C_x (-0.25)

and C_x (0.25). Note that with this calculation of the

15   integral components K_i (x_s, x_e), the above Expression (111)

is employed.

     Subsequently, the integral component calculation unit

3123 converts each of the 24 integral components K_i (x_s, x_e)

calculated into the corresponding integral components K_i (l)

20   in accordance with Expression (115), and generates an

integral component table including the 24 integral

components K_i (l) converted (i.e., 6 K_i (1), 6 K_i (2), 6 K_i

(3), and 6 K_i (4)).

     Note that the sequence of the processing in step S3102

25   and the processing in step S3103 is not restricted to the

example in Fig. 93, the processing in step S3103 may be executed first, or the processing in step S3102 and the processing in step S3103 may be executed simultaneously.

Next, in step S3104, the output pixel value calculation
5   unit 3124 calculates the output pixel values M (1) through M (4) respectively based on the features table generated by the features storage unit 3122 at the processing in step S3102, and the integral component table generated by the integral component calculation unit 3123 at the processing
10   in step S3103.

Specifically, in this case, the output pixel value calculation unit 3124 calculates each of the pixel value M (1) of the pixel 3111 (pixel of mode number 1), the pixel value M (2) of the pixel 3112 (pixel of mode number 2), the
15   pixel value M (3) of the pixel 3113 (pixel of mode number 3), and the pixel value M (4) of the pixel 3114 (pixel of mode number 4) by calculating the right sides of the following Expression (116) through Expression (119) corresponding to the above Expression (110).

$$M(1) = \sum_{i=0}^{5} w_i k_i (1)$$
20

$$\dots (116)$$

$$M(2) = \sum_{i=0}^{5} w_i k_i (2)$$

$$\dots (117)$$

$$M(3) = \sum_{i=0}^{5} w_i k_i(3)$$

$$\ldots (118)$$

$$M(4) = \sum_{i=0}^{5} w_i k_i(4)$$

$$\ldots (119)$$

5   In step S3105, the output pixel value calculation unit 3124 determines regarding whether or not the processing of all the pixels has been completed.

In step S3105, in the event that determination is made that the processing of all the pixels has not been completed,

10   the processing returns to step S3102, wherein the subsequent processing is repeatedly performed. That is to say, the pixels that have not become a pixel of interest are sequentially taken as a pixel of interest, and the processing in step S3102 through S3104 is repeatedly

15   performed.

In the event that the processing of all the pixels has been completed (in step S3105, in the event that determination is made that the processing of all the pixels has been completed), the output pixel value calculation unit

20   3124 outputs the image in step S3106. Then, the image generating processing ends.

Next, description will be made regarding the differences between the output image obtained by employing

the one-dimensional reintegration method and the output

image obtained by employing another method (conventional

classification adaptation processing) regarding a

predetermined input image with reference to Fig. 94 through

5   Fig. 101.

Fig. 94 is a diagram illustrating the original image of

the input image, and Fig. 95 illustrates image data

corresponding to the original image in Fig. 94. In Fig. 95,

the axis in the vertical direction in the drawing represents

10   pixel values, and the axis in the lower right direction in

the drawing represents the X direction serving as one

direction of the spatial directions of the image, and the

axis in the upper right direction in the drawing represents

the Y direction serving as the other direction of the

15   spatial directions of the image. Note that the respective

axes in later-described Fig. 97, Fig. 99, and Fig. 101

corresponds to the axes in Fig. 95.

Fig. 96 is a diagram illustrating an example of an

input image. The input image illustrated in Fig. 96 is an

20   image generated by taking the mean of the pixel values of

the pixels belonged to a block made up of 2 × 2 pixels shown

in Fig. 94 as the pixel value of one pixel. That is to say,

the input image is an image obtained by integrating the

image shown in Fig. 94 in the spatial direction, which

25   imitates the integration property of a sensor. Also, Fig.

97 illustrates image data corresponding to the input image in Fig. 96.

The original image illustrated in Fig. 94 includes a fine-line image inclined almost 5° clockwise from the

5 vertical direction. Similarly, the input image illustrated in Fig. 96 includes a fine-line image inclined almost 5° clockwise from the vertical direction.

Fig. 98 is a diagram illustrating an image (hereafter, the image illustrated in Fig. 98 is referred to as the

10 original image) obtained by subjecting the input image illustrated in Fig. 96 to conventional class classification adaptation processing. Also, Fig. 99 illustrates image data corresponding to the conventional image.

Note that the class classification adaptation

15 processing is made up of classification processing and adaptation processing, data is classified based on the property thereof by the class classification processing, and is subjected to the adaptation processing for each class, as described above. With the adaptation processing, for

20 example, a low-quality or standard-quality image is subjected to mapping using a predetermined tap coefficient so as to be converted into a high-quality image.

Fig. 100 is a diagram illustrating an image (hereafter, the image illustrated in Fig. 100 is referred to as a

25 reintegration image) obtained by applying the one-

dimensional reintegration method, to the input image

illustrated in Fig. 96. Also, Fig. 101 illustrates image

data corresponding to the reintegration image.

It can be understood that upon the conventional image

5   in Fig. 98 being compared with the reintegration image in

Fig. 100, a fine-line image is different from that in the

original image in Fig. 94 in the conventional image, but on

the other hand, the fine-line image is almost the same as

that in the original image in Fig. 94 in the reintegration

10   image.

This difference is caused by a difference wherein the

conventional class classification adaptation processing is a

method for performing processing on the basis (origin) of

the input image in Fig. 96, but on the other hand, the one-

15   dimensional reintegration method is a method for estimating

the original image in Fig. 94 (generating the approximation

function f(x) corresponding to the original image) in light

of continuity of a fine line, and performing processing

(performing reintegration so as to calculate pixel values)

20   on the basis (origin) of the original image estimated.

Thus, with the one-dimensional reintegration method,

the output image (pixel value) is generated by integrating

the approximation function f(x) in an arbitrary range, using

an approximation function f(x) such as a primary polynomial

25   generated by a one-dimensional approximation method (the

approximation function f(x) of the X-cross section waveform

F(x) of the actual world) as a standard (origin).

Accordingly, with the one-dimensional reintegration

method, it becomes possible to output an image more similar

5   to the original image (the light signal in the actual world

1 which is to be cast in the sensor 2) in comparison with

the conventional other methods.

Also, with the one-dimensional reintegration method, as

described above, the integral range is arbitrary, and

10   accordingly, it becomes possible to create resolution

(temporal resolution or spatial resolution) different from

the resolution of an input image by varying the integral

range. That is to say, it becomes possible to generate an

image having arbitrary powered resolution as well as an

15   integer value as to the resolution of the input image.

Further, the one-dimensional reintegration method

enables calculation of an output image (pixel values) with

less calculation processing amount than other reintegration

methods.

20   Next, description will be made regarding a two-

dimensional reintegration method with reference to Fig. 102

through Fig. 108.

The two-dimensional reintegration method is based on

condition that the approximation function f(x, y) has been

25   generated with the two-dimensional polynomial approximating

method.

That is to say, for example, it is an assumption that
the image function F(x, y, t) representing the light signal
in the actual world 1 (Fig. 89) having continuity in the
5   spatial direction represented with the gradient G_F has been
approximated with a waveform projected in the spatial
directions (X direction and Y direction), i.e., the waveform
F(x, y) on the X-Y plane has been approximated with the
approximation function f(x, y) serving as a n-dimensional (n
10   is an arbitrary integer) polynomial, such as shown in Fig.
102.

In Fig. 102, the horizontal direction represents the X
direction serving as one direction in the spatial directions,
the upper right direction represents the Y direction serving
15   as the other direction in the spatial directions, and the
vertical direction represents light levels, respectively in
the drawing. G_F represents gradient as continuity in the
spatial directions.

Note that with the example in Fig. 102, the direction
20   of continuity is taken as the spatial directions (X
direction and Y direction), so the projection function of a
light signal to be approximated is taken as the function F(x,
y), but as described later, the function F(x, t) or function
F(y, t) may be a target of approximation according to the
25   direction of continuity.

In the case of the example in Fig. 102, with the two-dimensional reintegration method, the output pixel value M is calculated as the following Expression (120).

$$M = G_e \times \int_{y_s}^{y_e} \int_{x_s}^{x_e} f(x, y) \, dxdy$$

5

$$\ldots (120)$$

Note that in Expression (120), y_s represents an integration start position in the Y direction, and y_e represents an integration end position in the Y direction. Similarly, x_s represents an integration start position in 10 the X direction, and x_e represents an integration end position in the X direction. Also, G_e represents a predetermined gain.

In Expression (120), an integral range can be set arbitrarily, and accordingly, with the two-dimensional 15 reintegration method, it becomes possible to create pixels having an arbitrary powered spatial resolution as to the original pixels (the pixels of an input image from the sensor 2 (Fig. 89)) without deterioration by appropriately changing this integral range.

20   Fig. 103 represents a configuration example of the image generating unit 103 employing the two-dimensional reintegration method.

As shown in Fig. 103, the image generating unit 103 in this example includes a conditions setting unit 3201,

features storage unit 3202, integral component calculation unit 3203, and output pixel value calculation unit 3204.

The conditions setting unit 3201 sets the number of dimensions n of the approximation function $f(x, y)$ based on the actual world estimating information (with the example in Fig. 103, the features of the approximation function $f(x, y)$) supplied from the actual world estimating unit 102.

The conditions setting unit 3201 also sets an integral range in the case of reintegrating the approximation function $f(x, y)$ (in the case of calculating an output pixel value). Note that an integral range set by the conditions setting unit 3201 does not need to be the vertical width or the horizontal width of a pixel. For example, the approximation function $f(x, y)$ is integrated in the spatial directions (X direction and Y direction), and accordingly, a specific integral range can be determined as long as the relative size (power of spatial resolution) of an output pixel (pixel to be generated from now by the image generating unit 103) as to the spatial size of each pixel of an input image from the sensor 2 is known. Accordingly, the conditions setting unit 3201 can set, for example, a spatial resolution power as an integral range.

The features storage unit 3202 temporally stores the features of the approximation function $f(x, y)$ sequentially supplied from the actual world estimating unit 102.

Subsequently, upon the features storage unit 3202 storing all of the features of the approximation function f(x, y), the features storage unit 3202 generates a features table including all of the features of the approximation function

5   f(x, y), and supplies this to the output pixel value calculation unit 3204.

Now, description will be made regarding the details of the approximation function f(x, y).

For example, now, let us say that the light signals

10 (light signals represented with the wave F (x, y)) in the actual world 1 (Fig. 89) having continuity in the spatial directions represented with the gradient G_F shown in Fig. 102 described above have been detected by the sensor 2 (Fig. 89), and have been output as an input image (pixel values).

15   Further, for example, let us say that the data continuity detecting unit 101 (Fig. 3) has subjected a region 3221 of an input image made up of 20 pixels in total (20 squares represented with a dashed line in the drawing) of 4 pixels in the X direction and also 5 pixels in the Y

20 direction of this input image to the processing thereof, and has output an angle θ (angle θ generated between the direction of data continuity represented with the gradient G_f corresponding to the gradient G_F and the X direction) as one of data continuity information, as shown in Fig. 104.

25   Note that as viewed from the actual world estimating

unit 102, the data continuity detecting unit 101 should

simply output the angle θ at a pixel of interest, and

accordingly, the processing region of the data continuity

detecting unit 101 is not restricted to the above region

5   3221 in the input image.

Also, with the region 3221 in the input image, the

horizontal direction in the drawing represents the X

direction serving as one direction of the spatial directions,

and the vertical direction in the drawing represents the Y

10 direction serving the other direction of the spatial

directions.

Further, in Fig. 104, a pixel, which is the second

pixel from the left, and also the third pixel from the

bottom, is taken as a pixel of interest, and an (x, y)

15 coordinates system is set so as to take the center of the

pixel of interest as the origin (0, 0). A relative distance

(hereafter, referred to as a cross-sectional direction

distance) in the X direction as to a straight line (straight

line of the gradient G_f representing the direction of data

20 continuity) having an angle θ passing through the origin (0,

0) is taken as x'.

Further, in Fig. 104, the graph on the right side

represents the approximation function $f(x')$ serving as a n-

dimensional (n is an arbitrary integer) polynomial, which is

25 a function approximating a one-dimensional waveform

(hereafter, referred to as an X cross-sectional waveform F(x')) wherein the image function F(x, y, t) of which variables are positions x, y, and z on the three-dimensional space, and point-in-time t is projected in the X direction

5 at an arbitrary position y in the Y direction. Of the axes in the graph on the right side, the axis in the horizontal direction in the drawing represents a cross-sectional direction distance, and the axis in the vertical direction in the drawing represents pixel values.

10 In this case, the approximation function f(x') shown in Fig. 104 is a n-dimensional polynomial, so is represented as the following Expression (121).

$$f(x') = w_0 + w_1 x' + w_2 x' + \cdots + w_n x'^n = \sum_{i=0}^{n} w_i x'^i$$

$$\cdots (121)$$

15 Also, since the angle θ is determined, the straight line having angle θ passing through the origin (0, 0) is uniquely determined, and a position x_1 in the X direction of the straight line at an arbitrary position y in the Y direction is represented as the following Expression (122). However,

20 in Expression (122), s represents cot θ.

$$x_1 = s \times y$$

$$\cdots (122)$$

That is to say, as shown in Fig. 104, a point on the straight line corresponding to continuity of data

represented with the gradient G_f is represented with a coordinate value (x_1, y).

The cross-sectional direction distance x' is represented as the following Expression (123) using Expression (122).

$$x' = x - x_1 = x - s \times y$$

$$\quad \ldots (123)$$

Accordingly, the approximation function $f(x, y)$ at an arbitrary position (x, y) within the input image region 3221 is represented as the following Expression (124) using Expression (121) and Expression (123).

$$f(x, y) = \sum_{i=0}^{n} w_i (x - s \times y)$$

$$\quad \ldots (124)$$

Note that in Expression (124), w_i represents the features of the approximation function $f(x, y)$.

Now, description will return to Fig. 103, wherein the features w_i included in Expression (124) are supplied from the actual world estimating unit 102, and stored in the features storage unit 3202. Upon the features storage unit 3202 storing all of the features w_i represented with Expression (124), the features storage unit 3202 generates a features table including all of the features w_i, and supplies this to the output pixel value calculation unit 3204.

Also, upon the right side of the above Expression (120) being expanded (calculated) by substituting the approximation function f(x, y) of Expression (124) for the approximation function f(x, y) in the right side of Expression (120), the output pixel value M is represented as the following Expression (125).

$$M = G_e \times \sum_{i=0}^{n} w_i \times \frac{\{(x_e - s \times y_e)^{i+2} - (x_e - s \times y_s)^{i+2} - (x_s - s \times y_e)^{i+2} + (x_s - s \times y_s)^{i+2}\}}{s(i+1)(i+2)}$$

$$= \sum_{i=0}^{n} w_i \times k_i (x_s, x_e, y_s, y_e)$$

$$\cdots (125)$$

In Expression (125), $K_i (x_s, x_e, y_s, y_e)$ represent the integral components of the i-dimensional term. That is to say, the integral components $K_i (x_s, x_e, y_s, y_e)$ are such as shown in the following Expression (126).

$$k_i (x_s, x_e, y_s, y_e)$$

$$= G_e \times \frac{\{(x_e - s \times y_e)^{i+2} - (x_e - s \times y_s)^{i+2} - (x_s - s \times y_e)^{i+2} + (x_s - s \times y_s)^{i+2}\}}{s(i+1)(i+2)}$$

$$\cdots (126)$$

The integral component calculation unit 3203 calculates the integral components $K_i (x_s, x_e, y_s, y_e)$.

Specifically, as shown in Expression (125) and Expression (126), the integral components $K_i (x_s, x_e, y_s, y_e)$ can be calculated as long as the start position x_s in the X direction and end position x_e in the X direction of an

integral range, the start position y_s in the Y direction and end position y_e in the Y direction of an integral range, variable s, gain G_e, and i of the i-dimensional term are known.

5   Of these, the gain G_e is determined with the spatial resolution power (integral range) set by the conditions setting unit 3201.

The range of i is determined with the number of dimensions n set by the conditions setting unit 3201.

10   A variable s is, as described above, cot θ, so is determined with the angle θ output from the data continuity detecting unit 101.

Also, each of the start position x_s in the X direction and end position x_e in the X direction of an integral range, and the start position y_s in the Y direction and end

15   position y_e in the Y direction of an integral range is determined with the center pixel position (x, y) and pixel width of an output pixel to be generated from now. Note that (x, y) represents a relative position from the center

20   position of the pixel of interest when the actual world estimating unit 102 generates the approximation function f(x).

Further, each of the center pixel position (x, y) and pixel width of an output pixel to be generated from now is

25   determined with the spatial resolution power (integral

range) set by the conditions setting unit 3201.

Accordingly, the integral component calculation unit 3203 calculates integral components K_i (x_s, x_e, y_s, y_e) based on the number of dimensions and the spatial resolution power

5 (integral range) set by the conditions setting unit 3201, and the angle θ of the data continuity information output from the data continuity detecting unit 101, and supplies the calculated result to the output pixel value calculation unit 3204 as an integral component table.

10 The output pixel value calculation unit 3204 calculates the right side of the above Expression (125) using the features table supplied from the features storage unit 3202, and the integral component table supplied from the integral component calculation unit 3203, and outputs the calculated

15 result to the outside as the output pixel value M.

Next, description will be made regarding image generating processing (processing in step S103 in Fig. 29) by the image generating unit 103 (Fig. 104) employing the two-dimensional reintegration method with reference to the

20 flowchart in Fig. 105.

For example, let us say that the light signals represented with the function F(x, y) shown in Fig. 102 have been cast in the sensor 2 so as to become an input image, and the actual world estimating unit 102 has already

25 generated the approximation function f(x, y) for

approximating the function F(x, y) with one pixel 3231 such

as shown in Fig. 106 as a pixel of interest at the

processing in step S102 in Fig. 29 described above.

Note that in Fig. 106, the pixel value (input pixel

5   value) of the pixel 3231 is taken as P, and the shape of the

pixel 3231 is taken as a square of which one side is 1 in

length. Also, of the spatial directions, the direction in

parallel with one side of the pixel 3231 is taken as the X

direction, and the direction orthogonal to the X direction

10   is taken as the Y direction. Further, a coordinates system

(hereafter, referred to as a pixel-of-interest coordinates

system) in the spatial directions (X direction and Y

direction) of which the origin is the center of the pixel

3231 is set.

15   Also, let us say that in Fig. 106, the data continuity

detecting unit 101, which takes the pixel 3231 as a pixel of

interest, has already output the angle θ as data continuity

information corresponding to continuity of data represented

with the gradient G_f at the processing in step S101 in Fig.

20   29 described above.

Description will return to Fig. 105, and in this case,

the conditions setting unit 3201 sets conditions (the number

of dimensions and an integral range) at step S3201.

For example, now, let us say that 5 has been set as the

25   number of dimensions, and also spatial quadruple density

(spatial resolution power to cause the pitch width of a
pixel to become half power in the upper/lower/left/right
sides) has been set as an integral range.

That is to say, in this case, it has been set that the
5 four pixel 3241 through pixel 3244 are created newly in a
range of -0.5 through 0.5 in the X direction, and also a
range of -0.5 through 0.5 in the Y direction (in the range
of the pixel 3231 in Fig. 106), such as shown in Fig. 107.
Note that in Fig. 107 as well, the same pixel-of-interest
10 coordinates system as that in Fig. 106 is shown.

Also, in Fig. 107, M (1) represents the pixel value of
the pixel 3241 to be generated from now, M (2) represents
the pixel value of the pixel 3242 to be generated from now,
M (3) represents the pixel value of the pixel 3243 to be
15 generated from now, and M (4) represents the pixel value of
the pixel 3244 to be generated from now.

Description will return to Fig. 105, in step S3202, the
features storage unit 3202 acquires the features of the
approximation function f (x, y) supplied from the actual
20 world estimating unit 102, and generates a features table.
In this case, the coefficients w_0 through w_5 of the
approximation function f (x) serving as a 5-dimensional
polynomial are supplied from the actual world estimating
unit 102, and accordingly, (w_0, w_1, w_2, w_3, w_4, w_5) is
25 generated as a features table.

In step S3203, the integral component calculation unit 3203 calculates integral components based on the conditions (the number of dimensions and an integral range) set by the conditions setting unit 3201, and the data continuity

5   information (angle θ) supplied from the data continuity detecting unit 101, and generates an integral component table.

Specifically, for example, let us say that numbers (hereafter, such a number is referred to as a mode number) 1

10   through 4 are respectively appended to the pixel 3241 through pixel 3244 to be generated from now, the integral component calculation unit 3203 calculates the integral components K_i (x_s, x_e, y_s, y_e) of the above Expression (125) as a function of 1 (however, 1 represents a mode number)

15   such as the integral components K_i (1) shown in the left side of the following Expression (127).

$$K_i (1) = K_i (x_s, x_e, y_s, y_e)$$

$$\dots (127)$$

Specifically, in this case, the integral components K_i

20   (1) shown in the following Expression (128) are calculated.

$$k_i (1) = k_i (-0.5, 0, 0, 0.5)$$
$$k_i (2) = k_i (0, 0.5, 0, 0.5)$$
$$k_i (3) = k_i (-0.5, 0, -0.5, 0)$$
$$k_i (4) = k_i (0, 0.5, -0.5, 0)$$

$$\dots (128)$$

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Note that in Expression (128), the left side represents
the integral components K_i (l), and the right side
represents the integral components K_i (x_s, x_e, y_s, y_e). That
is to say, in this case, l is any one of 1 thorough 4, and

5   also i is any one of 0 through 5, and accordingly, 24 K_i (l)
in total of 6 K_i (1), 6 K_i (2), 6 K_i (3), and 6 K_i (4) are
calculated.

More specifically, first, the integral component
calculation unit 3203 calculates the variable s (s = cot θ)

10 of the above Expression (122) using the angle θ supplied
from the data continuity detecting unit 101.

Next, the integral component calculation unit 3203
calculates the integral components K_i (x_s, x_e, y_s, y_e) of each
right side of the four expressions in Expression (128)

15 regarding i = 0 through 5 using the calculated variable s.
Note that with this calculation of the integral components
K_i (x_s, x_e, y_s, y_e), the above Expression (125) is employed.

Subsequently, the integral component calculation unit
3203 converts each of the 24 integral components K_i (x_s, x_e,

20 y_s, y_e) calculated into the corresponding integral components
K_i (l) in accordance with Expression (128), and generates an
integral component table including the 24 integral
components K_i (l) converted (i.e., 6 K_i (1), 6 K_i (2), 6 K_i
(3), and 6 K_i (4)).

25 Note that the sequence of the processing in step S3202

and the processing in step S3203 is not restricted to the
example in Fig. 105, the processing in step S3203 may be
executed first, or the processing in step S3202 and the
processing in step S3203 may be executed simultaneously.

5   Next, in step S3204, the output pixel value calculation
unit 3204 calculates the output pixel values M (1) through M
(4) respectively based on the features table generated by
the features storage unit 3202 at the processing in step
S3202, and the integral component table generated by the

10   integral component calculation unit 3203 at the processing
in step S3203.

Specifically, in this case, the output pixel value
calculation unit 3204 calculates each of the pixel value M
(1) of the pixel 3241 (pixel of mode number 1), the pixel

15   value M (2) of the pixel 3242 (pixel of mode number 2), the
pixel value M (3) of the pixel 3243 (pixel of mode number 3),
and the pixel value M (4) of the pixel 3244 (pixel of mode
number 4) shown in Fig. 107 by calculating the right sides
of the following Expression (129) through Expression (132)

20   corresponding to the above Expression (125).

$$M(1) = \sum_{i=0}^{n} w_i \times k_i(1)$$

...(129)

$$M(2) = \sum_{i=0}^{n} w_i \times k_i(2)$$

$$\ldots (130)$$

$$M(3) = \sum_{i=0}^{n} w_i \times k_i (3)$$

$$\ldots (131)$$

$$M(4) = \sum_{i=0}^{n} w_i \times k_i (4)$$

5
$$\ldots (132)$$

However, in this case, each n of Expression (129)
through Expression (132) becomes 5.

In step S3205, the output pixel value calculation unit
3204 determines regarding whether or not the processing of
10   all the pixels has been completed.

In step S3205, in the event that determination is made
that the processing of all the pixels has not been completed,
the processing returns to step S3202, wherein the subsequent
processing is repeatedly performed. That is to say, the
15   pixels that have not become a pixel of interest are
sequentially taken as a pixel of interest, and the
processing in step S3202 through S3204 is repeatedly
performed.

In the event that the processing of all the pixels has
20   been completed (in step S3205, in the event that
determination is made that the processing of all the pixels
has been completed), the output pixel value calculation unit
3204 outputs the image in step S3206. Then, the image

generating processing ends.

Thus, four pixels having higher spatial resolution than the input pixel 3231, i.e., the pixel 3241 through pixel 3244 (Fig. 107) can be created by employing the two-dimensional reintegration method as a pixel at the pixel 3231 of the input image (Fig. 106) from the sensor 2 (Fig. 89). Further, though not shown in the drawing, as described above, the image generating unit 103 can create a pixel having an arbitrary powered spatial resolution as to the input pixel 3231 without deterioration by appropriately changing an integral range, in addition to the pixel 3241 through pixel 3244.

As described above, as description of the two-dimensional reintegration method, an example for subjecting the approximation function $f(x, y)$ as to the spatial directions (X direction and Y direction) to two-dimensional integration has been employed, but the two-dimensional reintegration method can be applied to the time-space directions (X direction and t direction, or Y direction and t direction).

That is to say, the above example is an example in the case in which the light signals in the actual world 1 (Fig. 89) have continuity in the spatial directions represented with the gradient G_F such as shown in Fig. 102, and accordingly, an expression including two-dimensional

integration in the spatial directions (X direction and Y direction) such as shown in the above Expression (120) has been employed. However, the concept regarding two-dimensional integration can be applied not only to the

5   spatial direction but also the time-space directions (X direction and t direction, or Y direction and t direction).

In other words, with the two-dimensional polynomial approximating method serving as an assumption of the two-dimensional reintegration method, it is possible to perform

10   approximation using a two-dimensional approximation function f even in the case in which the image function F(x, y, t) representing the light signals has continuity in the time-space directions (however, X direction and t direction, or Y direction and t direction) as well as continuity in the

15   spatial directions.

Specifically, for example, in the event that there is an object moving horizontally in the X direction at uniform velocity, the direction of movement of the object is represented with like a gradient V_F in the X-t plane such as

20   shown in Fig. 108. In other words, it can be said that the gradient V_F represents the direction of continuity in the time-space directions in the X-t plane. Accordingly, the data continuity detecting unit 101 (Fig. 89) can output movement θ such as shown in Fig. 108 (strictly speaking,

25   though not shown in the drawing, movement θ is an angle

generated by the direction of data continuity represented with the gradient V_f corresponding to the gradient V_F and the X direction in the spatial direction) as data continuity information corresponding to the gradient V_F representing

5 continuity in the time-space directions in the X-t plane as well as the above angle θ (data continuity information corresponding to the gradient G_F representing continuity in the spatial directions in the X-Y plane).

Also, the actual world estimating unit 102 (Fig. 89)

10 employing the two-dimensional polynomial approximating method can calculate the coefficients (features) w_i of an approximation function f(x, t) with the same method as the above method by employing the movement θ instead of the angle θ described above. However, in this case, the

15 equation to be employed is not the above Expression (124) but the following Expression (133).

$$f(x, y) = \sum_{i=0}^{n} w_i (x - s \times t)$$

...(133)

Note that in Expression (133), s is cot θ (however, θ is

20 movement).

Accordingly, the image generating unit 103 (Fig. 89) employing the two-dimensional reintegration method can calculate the pixel value M by substituting the f (x, t) of the above Expression (133) for the right side of the

following Expression (134), and calculating this.

$$M = G_e \times \int_{t_s}^{t_e} \int_{x_s}^{x_e} f(x, t) \, dxdt$$

... (134)

Note that in Expression (134), t_s represents an

5   integration start position in the t direction, and t_e

represents an integration end position in the t direction.

Similarly, x_s represents an integration start position in

the X direction, and x_e represents an integration end

position in the X direction. G_e represents a predetermined

10   gain.

Alternately, an approximation function f(y, t) focusing

attention on the spatial direction Y instead of the spatial

direction X can be handled as the same way as the above

approximation function f(x, t).

15   Incidentally, in Expression (133), it becomes possible

to obtain data not integrated in the temporal direction,

i.e., data without movement blurring by regarding the t

direction as constant, i.e., by performing integration while

ignoring integration in the t direction. In other words,

20   this method may be regarded as one of two-dimensional

reintegration methods in that reintegration is performed on

condition that one certain dimension of the two-dimensional

approximation function f is constant, or in fact, may be

regarded as one of one-dimensional reintegration methods in

that one-dimensional reintegration in the X direction is performed.

Also, in Expression (134), an integral range may be set arbitrarily, and accordingly, with the two-dimensional

5 reintegration method, it becomes possible to create a pixel having an arbitrary powered resolution as to the original pixel (pixel of an input image from the sensor 2 (Fig. 89)) without deterioration by appropriately changing this integral range.

10 That is to say, with the two-dimensional reintegration method, it becomes possible to create temporal resolution by appropriately changing an integral range in the temporal direction t. Also, it becomes possible to create spatial resolution by appropriately changing an integral range in

15 the spatial direction X (or spatial direction Y). Further, it becomes possible to create both temporal resolution and spatial resolution by appropriately changing each integral range in the temporal direction t and in the spatial direction X.

20 Note that as described above, creation of any one of temporal resolution and spatial resolution may be performed even with the one-dimensional reintegration method, but creation of both temporal resolution and spatial resolution cannot be performed with the one-dimensional reintegration

25 method in theory, which becomes possible only by performing

- 320 -

two-dimensional or more reintegration. That is to say,

creation of both temporal resolution and spatial resolution

becomes possible only by employing the two-dimensional

reintegration method and a later-described three-dimensional

5   reintegration method.

Also, the two-dimensional reintegration method takes

not one-dimensional but two-dimensional integration effects

into consideration, and accordingly, an image more similar

to the light signal in the actual world 1 (Fig. 89) may be

10 created.

Next, description will be made regarding a three-

dimensional reintegration method with reference to Fig. 109

and Fig. 110.

With the three-dimensional reintegration method, the

15 approximation function f(x, y, t) has been created using the

three-dimensional approximating method, which is an

assumption.

In this case, with the three-dimensional reintegration

method, the output pixel value M is calculated as the

20 following Expression (135).

$$M = G_e \times \int_{t_s}^{t_e} \int_{y_s}^{y_e} \int_{x_s}^{x_e} f(x, y, t)\,dx\,dy\,dt$$

...(135)

Note that in Expression (135), t_s represents an

integration start position in the t direction, and t_e

represents an integration end position in the t direction.

Similarly, y_s represents an integration start position in the Y direction, and y_e represents an integration end position in the Y direction. Also, x_s represents an

5 integration start position in the X direction, and x_e represents an integration end position in the X direction. G_e represents a predetermined gain.

Also, in Expression (135), an integral range may be set arbitrarily, and accordingly, with the three-dimensional

10 reintegration method, it becomes possible to create a pixel having an arbitrary powered time-space resolution as to the original pixel (pixel of an input image from the sensor 2 (Fig. 89)) without deterioration by appropriately changing this integral range. That is to say, upon the integral

15 range in the spatial direction being reduced, a pixel pitch can be reduced without restraint. On the other hand, upon the integral range in the spatial direction being enlarged, a pixel pitch can be enlarged without restraint. Also, upon the integral range in the temporal direction being reduced,

20 temporal resolution can be created based on an actual waveform.

Fig. 109 represents a configuration example of the image generating unit 103 employing the three-dimensional reintegration method.

25 As shown in Fig. 109, this example of the image

generating unit 103 includes a conditions setting unit 3301,
features storage unit 3302, integral component calculation
unit 3303, and output pixel value calculation unit 3304.

The conditions setting unit 3301 sets the number of
5   dimensions n of the approximation function $f(x, y, t)$ based
on the actual world estimating information (with the example
in Fig. 109, features of the approximation function $f(x, y, t)$) supplied from the actual world estimating unit 102.

The conditions setting unit 3301 sets an integral range
10   in the case of reintegrating the approximation function $f(x, y, t)$ (in the case of calculating output pixel values).
Note that an integral range set by the conditions setting
unit 3301 needs not to be the width (vertical width and
horizontal width) of a pixel or shutter time itself. For
15   example, it becomes possible to determine a specific
integral range in the spatial direction as long as the
relative size (spatial resolution power) of an output pixel
(pixel to be generated from now by the image generating unit
103) as to the spatial size of each pixel of an input image
20   from the sensor 2 (Fig. 89) is known. Similarly, it becomes
possible to determine a specific integral range in the
temporal direction as long as the relative time (temporal
resolution power) of an output pixel value as to the shutter
time of the sensor 2 (Fig. 89) is known. Accordingly, the
25   conditions setting unit 3301 can set, for example, a spatial

resolution power and temporal resolution power as an

integral range.

The features storage unit 3302 temporally stores the

features of the approximation function f(x, y, t)

5   sequentially supplied from the actual world estimating unit

102. Subsequently, upon the features storage unit 3302

storing all of the features of the approximation function

f(x, y, t), the features storage unit 3302 generates a

features table including all of the features of the

10   approximation function f(x, y, t), and supplies this to the

output pixel value calculation unit 3304.

Incidentally, upon the right side of the approximation

function f(x, y) of the right side of the above Expression

(135) being expanded (calculated), the output pixel value M

15   is represented as the following Expression (136).

$$M = \sum_{i=0}^{n} w_i \times k_i \left(x_s, x_e, y_s, y_e, t_s, t_e \right)$$

$$\ldots (136)$$

In Expression (136), K_i (x_s, x_e, y_s, y_e, t_s, t_e)

represents the integral components of the i-dimensional term.

20   However, x_s represents an integration range start position

in the X direction, x_e represents an integration range end

position in the X direction, y_s represents an integration

range start position in the Y direction, y_e represents an

integration range end position in the Y direction, t_s

represents an integration range start position in the t

direction, and t_e represents an integration range end

position in the t direction, respectively.

The integral component calculation unit 3303 calculates

5   the integral components K_i $(x_s,$ $x_e,$ $y_s,$ $y_e,$ $t_s,$ $t_e)$.

Specifically, the integral component calculation unit

3303 calculates the integral components K_i $(x_s,$ $x_e,$ $y_s,$ $y_e,$ $t_s,$

$t_e)$ based on the number of dimensions and the integral range

(spatial resolution power or temporal resolution power) set

10   by the conditions setting unit 3301, and the angle θ or

movement θ of the data continuity information output from

the data continuity detecting unit 101, and supplies the

calculated results to the output pixel value calculation

unit 3304 as an integral component table.

15   The output pixel value calculation unit 3304 calculates

the right side of the above Expression (136) using the

features table supplied from the features storage unit 3302,

and the integral component table supplied from the integral

component calculation unit 3303, and outputs the calculated

20   result to the outside as the output pixel value M.

Next, description will be made regarding image

generating processing (processing in step S103 in Fig. 29)

by the image generating unit 103 (Fig. 109) employing the

three-dimensional reintegration method with reference to the

25   flowchart in Fig. 110.

For example, let us say that the actual world estimating unit 102 (Fig. 89) has already generated an approximation function f(x, y, t) for approximating the light signals in the actual world 1 (Fig. 89) with a

5 predetermined pixel of an input image as a pixel of interest at the processing in step S102 in Fig. 29 described above.

Also, let us say that the data continuity detecting unit 101 (Fig. 89) has already output the angle θ or movement θ as data continuity information with the same

10 pixel as the actual world estimating unit 102 as a pixel of interest at the processing in step S101 in Fig. 29.

In this case, the conditions setting unit 3301 sets conditions (the number of dimensions and an integral range) at step S3301 in Fig. 110.

15 In step S3302, the features storage unit 3302 acquires the features w_i of the approximation function f(x, y, t) supplied from the actual world estimating unit 102, and generates a features table.

In step S3303, the integral component calculation unit

20 3303 calculates integral components based on the conditions (the number of dimensions and an integral range) set by the conditions setting unit 3301, and the data continuity information (angle θ or movement θ) supplied from the data continuity detecting unit 101, and generates an integral

25 component table.

Note that the sequence of the processing in step S3302 and the processing in step S3303 is not restricted to the example in Fig. 110, the processing in step S3303 may be executed first, or the processing in step S3302 and the

5 processing in step S3303 may be executed simultaneously.

Next, in step S3304, the output pixel value calculation unit 3304 calculates each output pixel value based on the features table generated by the features storage unit 3302 at the processing in step S3302, and the integral component

10 table generated by the integral component calculation unit 3303 at the processing in step S3303.

In step S3305, the output pixel value calculation unit 3304 determines regarding whether or not the processing of all the pixels has been completed.

15 In step S3305, in the event that determination is made that the processing of all the pixels has not been completed, the processing returns to step S3302, wherein the subsequent processing is repeatedly performed. That is to say, the pixels that have not become a pixel of interest are

20 sequentially taken as a pixel of interest, and the processing in step S3302 through S3304 is repeatedly performed.

In the event that the processing of all the pixels has been completed (in step S3305, in the event that

25 determination is made that the processing of all the pixels

has been completed), the output pixel value calculation unit 3304 outputs the image in step S3306. Then, the image generating processing ends.

Thus, in the above Expression (135), an integral range
5 may be set arbitrarily, and accordingly, with the three-dimensional reintegration method, it becomes possible to create a pixel having an arbitrary powered resolution as to the original pixel (pixel of an input image from the sensor 2 (Fig. 89)) without deterioration by appropriately changing
10 this integral range.

That is to say, with the three-dimensional reintegration method, appropriately changing an integral range in the temporal direction enables temporal resolution to be created. Also, appropriately changing an integral
15 range in the spatial direction enables spatial resolution to be created. Further, appropriately changing each integral range in the temporal direction and in the spatial direction enables both temporal resolution and spatial resolution to be created.

20 Specifically, with the three-dimensional reintegration method, approximation is not necessary when degenerating three dimension to two dimension or one dimension, thereby enabling high-precision processing. Also, movement in an oblique direction may be processed without degenerating to
25 two dimension. Further, no degenerating to two dimension

enables process at each dimension. For example, with the

two-dimensional reintegration method, in the event of

degenerating in the spatial directions (X direction and Y

direction), process in the t direction serving as the

5   temporal direction cannot be performed. On the other hand,

with the thee-dimensional reintegration method, any process

in the time-space directions may be performed.

Note that as described above, creation of any one of

temporal resolution and spatial resolution may be performed

10   even with the one-dimensional reintegration method, but

creation of both temporal resolution and spatial resolution

cannot be performed with the one-dimensional reintegration

method in theory, which becomes possible only by performing

two-dimensional or more reintegration. That is to say,

15   creation of both temporal resolution and spatial resolution

becomes possible only by employing the above two-dimensional

reintegration method and the three-dimensional reintegration

method.

Also, the three-dimensional reintegration method takes

20   not one-dimensional and two-dimensional but three-

dimensional integration effects into consideration, and

accordingly, an image more similar to the light signal in

the actual world 1 (Fig. 89) may be created.

Next, with the signal processing device 4 shown in Fig.

25   3, data continuity is detected at the data continuity

detecting unit 101, and estimation of actual world 1 signal

waveforms, i.e., for example, an approximation function

approximating the X-cross-section waveform F(x), is obtained

at the actual world estimating unit 102, based on the

5 continuity.

Thus, waveform estimation of actual world 1 signals is

performed at the signal processing device 4 based on

continuity, so in the event that the continuity detected by

the data continuity detecting unit 101 is incorrect or

10 detection precision thereof is poor, the estimation

precision of the waveform of the actual world 1 signals is

also poor.

Also, the signal processing device 4 performs signal

processing based on continuity which actual world 1 signals,

15 which is an image in this case, for example, have, signal

processing with better precision than signal processing with

other signal processing devices can be performed for the

parts of the actual world 1 signals where continuity exists,

and consequently, an image closer to the image corresponding

20 to the actual world 1 signals can be output.

However, the signal processing device 4 cannot perform

signal processing for parts of the actual world 1 signals

where no clear continuity exists at the same level of

precision as four parts were continuity does exist, since

25 the signal processing is being performed based on continuity,

and consequently, an image including error with regard to the image corresponding to the actual world 1 signals is output.

Accordingly, in order to obtain an image closer to the
5   image corresponding to the actual world 1 signals with the signal processing device 4, processing regions where signal processing with the signal processing device 4 is to be performed, precision of the continuity used with the signal processing device 4, and so forth, are issues.

10   Here, Fig. 111 illustrates the configuration example of another embodiment of the signal processing device 4 in Fig. 1.

In Fig. 111, the signal processing device 4 comprises a processing region setting unit 10001, a continuity setting
15   unit 10002, an actual world estimating unit 10003, an image generating unit 10004, an image display unit 10005, and a user I/F (Interface) 10006.

With the signal processing device 4 of which the configuration is shown in Fig. 111, image data (input image)
20   which is an example of the data 3, is input from the sensor 2 (Fig. 1), and the input image is supplied to the processing region setting unit 10001, the continuity setting unit 10002, the actual world estimating unit 10003, the image generating unit 10004, and the image display unit
25   10005.

The processing region setting unit 10001 sets the processing region for the input image, and supplies processing region information identifying the processing region to the continuity setting unit 10002, the actual world estimating unit 10003, and the image generating unit 10004.

The continuity setting unit 10002 recognizes the processing region in the input image from the processing region information supplied from the processing regions setting unit 10001, sets the continuity of the actual world 1 signals lost from the image data at that processing region, and supplies continuity information representing that continuity to the actual world estimating unit 10003 and the image generating unit 10004.

The actual world estimating unit 10003 is configured of a model generating unit 10011, equation generating unit 10012, and actual world waveform estimating unit 10013, and estimates the actual world 1 signals from the image data within the processing region, according to the continuity of the corresponding actual world 1 signals.

That is to say, the model generating unit 10011 recognizes the processing region in the input image from the processing region information supplied from the processing region setting unit 10001, generates a function serving as a model which models the relation between the pixel values of

the pixels within the processing region and the actual world
1 signals, according to the pixels making up the processing
region and the continuity of the actual world 1 signals
corresponding to the image data in the processing region,

5   and supplies this to the equation generating unit 10012.

The question generating unit 10012 recognizes the
processing region in the input image from the processing
region information supplied from the processing regions
setting unit 10001. Further, the equation generating unit

10 10012 substitutes the pixel values of each of the pixels
making up the processing region into the function serving as
a model that has been supplied from the model generating
unit 10011, thereby generating an equation, which is
supplied to the actual world waveform estimating unit 10013.

15 The actual world waveform estimating unit 10013
estimates the waveform of the actual world 1 signals, by
computing the equation supplied from the equation generating
unit 10012. That is to say, the actual world waveform
estimating unit 10013 obtains an approximation function

20 approximating the actual world 1 signals by solving the
equation supplied from the equation generating unit 10012,
and supplies the approximation function to the image
generating unit 10004, as estimation results of the waveform
of the actual world 1 signals. Note that approximation

25 function approximating the actual world 1 signals include

functions with constant function values, regardless of argument value.

The image generating unit 10004 generates signals closer approximating the actual world 1 signals, based on the approximation function representing the waveform of the actual world 1 signals estimated at the actual world estimating unit 10003, and the continuity information supplied from the continuity setting unit 10002. That is to say, the image generating unit 10004 recognizes the .

processing region in the input image from the processing region information supplied from the processing region setting unit 10001, and generates image data closer approximating the image corresponding to the actual world 1 signals with regard to the processing region, based on the approximation function supplied from (the actual world waveform estimating unit 10013) of the actual world estimating unit 10003, and the continuity information supplied from the continuity setting unit 10002.

Further, the image generating unit 10004 synthesizes the input image and image data generated based on the approximation function (hereafter referred to as approximation image as appropriate), generates an image wherein the portion of the processing region of the input image has been substituted with the approximation image, and supplies the image as an output image to the image display

unit 10005.

The image display unit 10005 is configured of a CRT
(Cathode Ray Tube) or an LCD (Liquid Crystal Display), and
displays input images, or output images supplied from the
5   image generating unit 10004.

Note that the image display unit 10005 can be
configured of single or multiple CRTs or LCDs. In the event
of configuring the image display unit 10005 with a single
CRT or LCD, an arrangement maybe made wherein the screen of
10   the single CRT or LCD is divided into multiple screens, with
input images displayed on one screen and output images
displayed on another screen. Further, in the event of
configuring the image display unit 10005 of multiple CRTs or
LCDs, an arrangement may be made wherein input images are
15   displayed on one CRT or LCD, and outputs images are
displayed on another CRT or LCD.

Also, the image display unit 10005 performs display of
various types in accordance with the output of the user I/F
10006. That is to say, the image display unit 10005
20   displays a cursor, for example, and in the event that the
user operates the user I/F 10006 so as to move the cursor,
the cursor is moved in accordance with the operations
thereof. Also, in the event that the user operates the user
I/F 10006 so as to select a predetermined range, the image
25   display unit 10005 displays a frame surrounding the range

selected on the screen in accordance with the operations thereof.

The user I/F 10006 is operated by the user, and in accordance with the user operations, supplies information

5   relating to at least one of, for example, processing range, continuity, and real world signals, to the processing region setting unit 10001, continuity setting unit 10002, or actual world estimating unit 10003.

That is to say, the user views an input image or output

10   image displayed on the image display unit 10005, and operates the user I/F 10006 so as to provide input with regard to the input image or output image. The user I/F 10006 is operated by the user, and in accordance with the user operations, supplies information relating to processing

15   range, continuity, or real world signals, to the processing region setting unit 10001, continuity setting unit 10002, or actual world estimating unit 10003, as assisting information for assisting the processing of the processing region setting unit 10001, continuity setting unit 10002, or actual

20   world estimating unit 10003.

Upon assisting information being supplied from the user I/F 10006, the processing region setting unit 10001, continuity setting unit 10002, or actual world estimating unit 10003 each perform setting of processing region,

25   setting of continuity, or estimation of actual world 1

signals, based on the assisting information.

Note however, that the processing region setting unit 10001, continuity setting unit 10002, or actual world estimating unit 10003, can each perform the setting of

5   processing region, setting of continuity, or estimation of actual world 1 signals, even without using the assisting information, i.e., even without the user operating the user I/F 10006.

Specifically, with the processing region setting unit

10   10001, processing can be performed in the same way as with the data continuity detecting unit 101 shown in Fig. 3, as described with reference to Fig. 30 to Fig. 48, wherein a continuity region is detected from the input image, and a rectangular (oblong) region surrounding the continuity

15   region is set as a processing region.

Also, with the continuity setting unit 10002, processing can be performed in the same way as with the data continuity detecting unit 101 shown in Fig. 3, as described with reference to Fig. 49 through Fig. 57, wherein data

20   continuity is detected from the input image, and the continuity of the corresponding actual world 1 signals is set based on the continuity of that data, i.e., for example, the data continuity is set as continuity of the actual world 1 signals with no change.

25   Further, with the actual world estimating unit 10003,

processing may be performed in the same way as with the
actual world estimating unit 102 shown in Fig. 3, as
described with reference to Fig. 58 through Fig. 88, where
actual world 1 signals are estimated from the image data of

5   the processing region set by the processing region setting
unit 10001, corresponding to the continuity set by the
continuity setting unit 10002. Note that while the data
continuity has been used for estimating actual world 1
signals that the actual world estimating unit 102 in Fig. 3,

10 an arrangement may be made wherein the continuity of
corresponding actual world 1 signals is used instead of the
data continuity for estimating actual world 1 signals.

   Next, the processing of the signal processing device 4
shown in Fig. 111 will be described with reference to the

15 flowchart in Fig. 112.

   First, in step S10001, the signal processing device 4
performs pre-processing, and the flow proceeds to step
S10002. That is to say, the signal processing device 4
supplies one frame or one field, for example, of the input

20 image, supplied from the sensor 2 (Fig. 1) as data 3, to the
processing region setting unit 10001, continuity setting
unit 10002, actual world estimating unit 10003, image
generating unit 10004, and image display unit 10005.
Further, the signal processing unit 4 causes the image

25 display unit 10005 to display the input image.

In step S10002, the user I/F 10006 determines whether
or not there has been some sort of user input, by the user
operating the user I/F 10006. In step S10002, in the event
that determination is made that there is no user input, i.e.,

5   in the event that the user has made no operations, step
S10003 through step S10005 are skipped, and the flow
proceeds to step S10006.

Also, in the event that determination is made in step
S10002 that there has been user input, i.e., in the event

10   that the user has viewed the input image displayed on the
image display unit 10005 and operated the user I/F 10006,
thereby making user input indicating some sort of
instruction or information, the flow proceeds to step S10003,
where the user I/F 10006 determines whether or not the user

15   input is ending instructions for instructing ending of the
processing of the signal processing device 4.

In the event that determination is made in step S10003
that the user input is ending instructions, the signal
processing device 4 ends processing.

20   Also, in the event that determination is made in step
S10003 that the user input is not ending instructions, the
flow proceeds to step S10004, where the user I/F 10006
determines whether or not the user input is assisting
information. In the event that determination is made in

25   step S10004 that the user input is not assisting information,

the flow skips step S10005, and proceeds to step S10006.

Also, in the event that determination is made in step S10004 that the user input is assisting information, the flow proceeds to step S10005, where the user I/F 10006

5   supplies the assisting information to the processing region setting unit 10001, continuity setting unit 10002, or actual world estimating unit 10006, and the flow proceeds to step S10006.

In step S10006, the processing region setting unit

10 10001 sets the processing region based on the input image, and supplies the processing region information identifying the processing region to the continuity setting unit 10002, actual world estimating unit 10003, and image generating unit 10004, and the flow proceeds to step S10007. Now, in

15 the event that assisting information has been supplied from the user I / F 10006 in that immediately-preceding step S10005, the processing region setting unit 10001 performs setting of the processing region using that assisting information.

20   In step S10007, the continuity setting unit 10002 recognizes the processing region in the input image, from the processing region information supplied from the processing region setting unit 10001. Further, the continuity setting unit 10002 sets continuity of the actual

25 world 1 signals that has been lost in the image data of the

processing region, and supplies continuity information
indicating the continuity thereof to the actual world
estimating unit 10003, and the flow proceeds to step S10008.
Now, in the event that assisting information has been

5   supplied from the user I / F 10006 in that immediately-
preceding step S10005, the continuity setting unit 10002
performs setting of continuity using that assisting
information.

In step S10008, the actual world estimating unit 10003

10   estimates actual world 1 signals regarding to the image data
with in the processing region of the input image, according
to the continuity of the corresponding actual world 1
signals.

That is to say, at the actual world estimating unit

15   10003, the model generating unit 10011 recognizes the
processing region in the input image, from the processing
region information supplied from the processing region
setting unit 10001, and also recognizes continuity of the
actual world 1 signals corresponding to the image data in

20   the processing region, from the continuity information
supplied from the continuity setting unit 10002. Further
the model generating unit 10011 generates a function serving
as a model modeling the relation between the pixel values of
each of the pixels within the processing region and the

25   actual world 1 signals, according to the pixels making up

the processing region in the input image, and the continuity of actual world 1 signals corresponding to the image data of the processing region, and supplies this to the equation generating unit 10012.

5   The equation generating unit 10012 recognizes the processing region in the input image from the processing region information supplied from the processing region setting unit 10001, and substitutes the pixel values of each of the pixels of the input image making up the processing

10   region into the function serving as the model which is supplied from the model generating unit 10011, thereby generating an equation for obtaining an approximation function approximating the actual world 1 signals, which is supplied to the actual world waveform estimating unit 10013.

15   The actual world waveform estimating unit 10013 estimates the waveform of the actual world 1 signals by computing the equation supplied from the equation generating unit 10012. That is, the actual world waveform estimating unit 10013 obtains the approximation function serving as a

20   model modeling the actual world 1 signals by solving the equation supplied from the equation generating unit 10012, and supplies the approximation function to the image generating unit 10004 as estimation results of the waveform of the actual world 1 signals.

25   Note that with the actual world estimating unit 10003,

in the event that assisting information has been supplied
from the user I/F 10006 in the immediately-preceding step
S10005, at the model generating unit 10011 and equation
generating unit 10012, processing is performed using that

5   assisting information.

Following processing of step S10008, the flow proceeds
to step S10009, where the image generating unit 10004
generates signals closer approximating the actual world 1
signals based on the approximation function approximating

10 the waveform of the actual world 1 signals supplied from
(the actual world waveform estimating unit 10013 of) the
actual world estimating unit 10003. That is to say, the
image generating unit 10004 recognizes the processing region
in the input image from the processing region information

15 supplied from the processing region setting unit 10001, and
with regard to this processing region, generates an
approximation image which is image data closer approximating
the image corresponding to the actual world 1 signals, based
on the approximation function supplied from the actual world

20 estimating unit 10003. Further the image generating unit
10004 generates, as an output image, an image wherein the
portion of the processing region of the input image has been
replaced with the approximation image, and supplies this to
the image display 10005, and the flow proceeds from step

25 S10009 to step S10010.

In step S10010, the image display unit 10005 displays the output image supplied from the image generating unit 10004 instead of the input image displayed in step S10001, or along with the input image, and the flow proceeds to step

5   S10011.

In step S10011, the user I/F 10006 determines whether or not there has been user input of some sort by the user operating the user I/F 10006, in the same way as with step S10002, and in the event that determination is made that

10   there has been no user input, i.e., in the event that the user has made no operations, the flow returns to step S10011, and awaits user input.

Also, in the event that determination is made in step S10011 that there has been user input, i.e., in the event

15   that the user has viewed the input image or output image displayed on the image display unit 10005 and operated the user I/F 10006, thereby making some sort of user input indicating instruction or information, the flow proceeds to step S10012, where the user I/F 10006 determines whether or

20   not the user input is ending instructions instructing ending of the processing of the signal processing device 4.

In the event that determination is made in step S10012 that the user input is ending instructions, the signal processing device 4 ends processing.

25   Also, in the event that determination is made in step

S10012 that the user input is not ending instructions, the flow proceeds to step S10013, where the user I/F 10006 determines whether or not the user input is assisting information. In the event that determination is made in step S10013 that the user input is not assisting information, the flow returns to step S10011, and the same processing is repeated thereafter.

Also, in step S10013, in the event that determination is made that the user input is assisting information, the flow returns to step S10005, and as described above, the user I/F 10006 supplies the assisting information to the processing region setting unit 10001, the continuity setting unit 10002, or the actual world estimating unit 10006. The flow then proceeds from step S10005 to step S10006, and hereafter the same processing is repeated.

As described above, with the signal processing device 4 shown in Fig. 111, assisting information for assisting the processing region setting unit 10001, the continuity setting unit 10002, or the actual world estimating unit 10006, is supplied from the user I/F 10006 to the processing region setting unit 10001, the continuity setting unit 10002, or the actual world estimating unit 10003 and processing region setting, continuity setting, or actual world 1 signals estimation is performed at the processing region setting unit 10001, the continuity setting unit 10002, or the actual

world estimating unit 10003 based on the assisting

information from the user I/F 10006, thereby improving the

processing precision of the processing region setting unit

10001, the continuity setting unit 10002, or the actual

5   world estimating unit 10003, and enabling, for example, a

high-quality output image meeting user preferences.

Next, various types of application examples of the

signal processing device 4 shown in Fig. 111 will be

described.

10   Fig. 113 illustrates a configuration example of an

embodiment of an application of the signal processing device

4 shown in Fig. 111.

An image of, for example, one frame or one field as the

data 3 from the sensor 2 is input into the signal processing

15   device 4 in Fig. 113.   Here, let us say that an object

having a predetermined shape is displayed in the input image,

such object moving in the horizontal direction (crosswise

direction) of the input image at a constant speed of v

pixels per shutter time (exposure time).   In other words,

20   regarding the input image, the object is moving in the

horizontal direction at the movement amount of v pixels, and

therefore because of the time integration effect of the

sensor 2, the light signal of the object and the light

signal of the portion other than the object are mixed (time

25   mixture), and thus, the image is blurred at portions such as

the borders of the object. With the signal processign device 4 shownh in Fig. 113, a high-quality outptu image is generated, wherein movement blurring due to such time mixture has been elimited from the input image.

5   In Fig. 113, the processing region setting unit 15011, the continuity setting unit 15012, the actual world estimating unit 15013, image generating unit 15014, image display unit 15015, and user I/F 15016, each correspond to the processing region setting unit 10001, the continuity

10   setting unit 10002, the actual world estimating unit 10003, image generating unit 10004, image display unit 10005, and user I/F 10006 shown in Fig. 111, and basically perform the same processing as the processing region setting unit 10001, the continuity setting unit 10002, the actual world

15   estimating unit 10003, image generating unit 10004, image display unit 10005, and user I/F 10006. Further, in Fig. 113, the actual world estimating unit 15013 comprises a model generating unit 15021, an equation generating unit 15022, and actual world waveform estimating unit 15023. The

20   model generating unit 15021, equation generating unit 15022, and actual world waveform estimating unit 15023 correspond to each of the model generating unit 10011, equation generating unit 10012, and actual world waveform estimating unit 10013 in Fig. 111, and basically perform the same

25   functions as each of the model generating unit 10011,

equation generating unit 10012, and actual world waveform
estimating unit 10013.

Note however, that in Fig. 113, the assisting
information which the user I/F 15016 outputs by the user
5   operating the user I/F 15016, is supplied only to the
equation generating unit 15022.

In other words, in Fig. 113, by operating the user I/F
15016, with the equation generating unit 15022, the user can
set the constraint conditions which constrain the relation
10 between each of the pixels of an image with no movement
blurring, which is an image of the actual world 1
corresponding to the input image, and when the user performs
an operation to set the constraint conditions, the user I/F
15016 supplies the constraint condition information
15 expressing the constraint conditions set by the operation to
the equation generating unit 15022.

Specifically, for example, a user who views an image
displayed on the image display unit 15015 reflecting a
blurring image guesses the original image, that is to say,
20 an image without movement blurring which is an image of the
actual world 1 corresponding to the input image. Also, for
example, the user guesses predetermined regions where
blurring is occurring as the edge portions, and guesses the
relation of the pixel values between each of the pixels (the
25 constraint conditions), such as the difference being large

between the pixel values (level) between the adjacent pixels
at the edge portions. Further, the user can set the
conditions suitable for the guessed relation of the pixels
value between each of the pixels into the equation
5   generating unit 15022, by operating the user I/F 15016.

Also, in Fig. 113, the processing region information,
which is supplied from the processing region setting unit
15011 to the actual world estimating unit 15013, is supplied
to the model generating unit 15021 and the equation
10 generating unit 15022 of the actual world estimating unit
15013. The model generating unit 15021 and the equation
generating unit 15022 recognize the processing region in the
input image from the processing region information which is
supplied from the processing region setting unit 15011.

15 The continuity setting unit 15012 sets a movement
amount (movement vector) in the input image as the
continuity information that an object is moving in the
horizontal direction of the image at the constant speed of v
pixels per shutter time, and supplies this movement amount v
20 as the continuity information to the model generating unit
15021 of the actual world estimating unit 15013.

The model generating unit 15021 generates an equation
(hereafter referred to as model equation as appropriate) as
a model (hereafter referred to as relation model as
25 appropriate), modeling the relation between the signal of

the actual world 1 and the pixel values of each of the
pixels of the movement blurring image as the input image
which considers the movement amount v as the continuity
information supplied from the continuity setting unit 15012,
5   regarding the processing region recognized by the processing
region information which is supplied from the processing
region setting unit 15011, and supplies the generated model
equation to the equation generating unit 15022.

The equation generating unit 15022 generates a
10   constraint condition Expression (hereafter referred to as
constraint condition expression as appropriate), based on
the constraint condition information supplied from the user
I/F 15016, and substitutes the pixel values of each of the
pixels of the input image comprising the processing region
15   into this constraint condition expression and the model
equation which is supplied from the model generating unit
15021 to the equation generating unit 15022, and thus,
generates an equation to find the approximation function as
a model (hereafter referred to as approximation model)
20   wherein the signal of the actual world 1 is modeled, and
supplies this to the actual world waveform estimating unit
15023.

The actual world waveform estimating unit 15023
estimates the waveform of the signal of the actual world 1,
25   by computing the equation supplied from the equation

generating unit 15022. In other words, the actual world

waveform estimating unit 15023 finds the approximation

function as an approximation model, and supplies the

approximation function to the image generating unit 15014 as

5   the estimation result of the signal waveform of the actual

world 1. Here, the approximation function which

approximates the signal of the actual world 1 has contained

a function value that is a fixed function, regardless of the

argument value.

10   The image generating unit 15014 recognizes the

processing region of the input image, based on the

processing region information supplied from the processing

region setting unit 15011. Also, the image generating unit

15014 generates a signal more closely approximating the

15   signal of the actual world 1, from the approximation

function supplied from the actual world waveform estimating

unit 15023, that is to say, generates an image with no

movement blurring, and replaces the image of the processing

region of the input image with an image wherein the image

20   has no movement blurring, generates this as an output image,

and supplies this to the image display unit 15015.

Next, the processing of the signal processing device 4

in Fig. 113 will be described with reference to the

flowchart in Fig. 114.

25   First, in step S15001, the signal processing device 4

performs pre-processing, and the flow proceeds to step
S15002. That is to say, the signal processing device 4
supplies one frame or one field, for example, of the input
image, supplied from the sensor 2 (Fig. 1) as data 3, to the

5   processing region setting unit 15011, continuity setting
unit 15012, actual world estimating unit 15013, image
generating unit 15014, and image display unit 15015.
Further, the signal processing unit 4 causes the image
display unit 15015 to display the input image.

10   In step S15002, the user I/F 15016 determines whether
or not there has been some sort of user input, by the user
operating the user I/F 15016. In step S15002, in the event
that determination is made that there is no user input, i.e.,
in the event that the user has made no operations, step

15   S15003 through step S15005 are skipped, and the flow
proceeds to step S15006.

     On the other hand, in step S15002, in the event that
determination is made that there has been user input, i.e.,
in the event that the user has viewed the input image

20   displayed on the image display unit 15015 and operated the
user I/F 15016, thereby making user input indicating some
sort of instruction or information, the flow proceeds to
step S15003, where the user I/F 15016 determines whether or
not the user input is user instructions instructing ending

25   of the processing of the signal processing device 4.

In the event that determination is made in step S15003 that the user input is ending instructions, the signal processing device 4 ends the processing.

Also, in the event that determination is made in step S15003 that the user input is not ending instructions, the flow proceeds to step S15004, where the user I/F 15016 determines whether or not the user input is constraint condition information. In the event that determination is made in step S15004 that the user input is not constraint condition information, step S15005 is skipped, and the flow proceeds to step S15006.

Also, in the event that determination is made in step S15004 that the user input is constraint condition information, the flow proceeds to step S15005, where the user I/F 15016 supplies the constraint condition information to the equation generating unit 15022, and the flow proceeds to step S15006.

In step S15006, the processing region setting unit 15011 sets the processing region based on the input image, and supplies the processing region information identifying the processing region to the continuity setting unit 15012, the model generating unit 15021 and the equation generating unit 15022 of the actual world estimating unit 15013, and image generating unit 15014, and the flow proceeds to step S15007. Now, the setting of the processing region in step

S15006 can be arranged by the user inputting the processing

region instruction information by operating the user I/F

15016, and can be performed based on this processing region

instruction information, or can be performed with no

5 processing region instruction information from the user.

In step S15007, the continuity setting unit 15012

recognizes the processing region in the input image, from

the processing region information supplied from the

processing region setting unit 15011. Further, the

10 continuity setting unit 15012 sets the continuity of the

signal of the actual world 1, of which one portion of

continuity has been lost of the image data of the processing

region, and the continuity information showing this

continuity is supplied to the model generating unit 15021 of

15 the actual world estimating unit 15013, and the flow

proceeds to step S15008. Here the continuity setting unit

15012 sets the movement amount v, expressing that the

movement is in the horizontal direction at a constant speed

of v pixels per shutter time (exposure time), as the

20 continuity information, and supplies this to the model

generating unit 15021 of the actual world estimating unit

15013. Here, the continuity setting unit 15012 sets the

movement amount showing only the movement size as continuity

information, under the premise that the object is moving in

25 a horizontal direction, but a movement vector showing the

size and direction of the movement of the object can be set
as continuity information as well. The setting of
continuity in step S15007 can be arranged by the user
inputting the continuity instruction information by
5   operating the user I/F 15016, and can be performed based on
this continuity instruction information, or can be performed
with no continuity instruction information from the user.

The actual world estimating unit 15013 performs actual
world estimating processing in step S15008. In other words,
10 with the actual world estimating unit 15013, the model
generating unit 15021 generates an equation (model equation)
as the model (relation model) wherein the relation of the
pixel values of each of the pixels of the input image which
has movement blurring and the signal of the actual world 1
15 is modeled, based on the movement amount v supplied from the
continuity setting unit 15012 in step S15007 and the
processing region information supplied from the processing
region setting unit 15011 in step S15006, and the generated
model is supplied to the equation generating unit 15022.

20 The equation generating unit 15022 generates a
constraint condition expression based on the constraint
condition information supplied from the user I/F 15016 in
step S15005, and further, generates an equation for finding
the approximation function of the model (approximation
25 model) wherein the signal of the actual world 1 is modeled,

from the constraint condition expression and the model

equation supplied from the model generating unit 15021 to

the equation generating unit 15022, and substitutes the

pixel values of each of the pixels of the input image into

5   this equation, and supplies this to the actual world

waveform estimating unit 15023.

The actual world waveform estimating unit 15023

estimates the waveform of the signal of the actual world 1,

that is to say, finds the approximation function as a model

10   which models the signal of the actual world 1, by

calculating the equation supplied from the equation

generating unit 15022, and supplies this approximation

function to the image generating unit 15014 as the

estimation result of the signal waveform of the actual world

15   1.

The actual world estimating processing of step S15008

will be described in detail later with reference to Fig. 130.

After the processing in step S15008, the flow proceeds

to step S15009, and the image generating unit 15014

20   generates a signal more closely approximating the signal

from the actual world 1, from the approximation function

supplied from the actual world waveform estimating unit

15023, that is to say, generates an image with no movement

blurring, and based on the processing region information

25   supplied from the processing region setting unit 15011,

replaces the portion of the processing region of the input

image with an image which has no movement blurring generated,

generates this as an output image, and supplies this to the

image display unit 15015, and the flow proceeds to step

5 S15010.

In step S15010, the image display unit 15015 displays

the output image supplied from the image generating unit

15014 instead of the input image displayed in step S15001,

or along with the input image, and the flow proceeds to step

10 S15011.

In step S15011, as with the case of step S15002, the

user I/F 12006 determines whether or not there has been some

sort of user input by the user operating the user I/F 15016,

and in the event that determination is made that there has

15 been no user input, i.e., in the event that the user has

made no operations, the flow returns to step S15011, and

awaits some sort of user input.

Also, in the event that determination is made in step

S15011 that there has been user input, i.e., in the event

20 that the user has viewed the input image or output image

displayed on the image display unit 15015 and operated the

user I/F 15016, thereby making user input representing some

sort of instructions or information, the flow proceeds to

step S15012, where the user I/F 15016 determines whether or

25 not the user input is ending instructions instructing ending

of the processing of the signal processing device 4.

In the event that determination is made in step S15012 that the user input is ending instructions, the signal processing device 4 ends processing.

5   On the other hand, in the event that determination is made in step S15012 that the user input is not ending instructions, the flow proceeds to step S15013, where the user I/F 15016 determines whether or not the user input is constraint condition information. In the event that

10   determination is made in step S15013 that the user input is not constraint condition information, the flow returns to step S15011, and the same processing is repeated thereafter.

Also, in step S15013, in the event that determination is made that the user input is constraint condition

15   information, the flow returns to step S15005, and as described above, the user I/F 15016 supplies the constraint condition information to the equation generating unit 15022. The flow then proceeds from step S15005 to step S15006, and hereafter the same processing is repeated.

20   Now, in the event that the signal processing device 4 repeats the processing of step S15005 through step S15013, the processing of the above-described step S15006 and S15007 are the same as that set by the first processing S15006 and S15007, and the same process as the first process may be

25   repeated, or may be skipped.

Thus, with the signal processing device 4 in Fig. 113, by finding an approximation function as a model wherein the signal of the actual world 1 is modeled, an output image of high image quality with no movement blurring can be

5   generated.

Also, by operating the user I/F 15016, the user can set constraint conditions which constrain the relation between each of the pixels in the original image having no movement blurring, and in the event that a new constraint condition

10   is input, an image without movement blurring can be requested again, and therefore an output image of high image quality according to the preference of the user can be easily acquired.

With the signal processing device 4 in Fig. 113, an

15   output image without movement blurring is generated by finding an approximation function which approximates the light signal of the actual world 1, but this output image can be viewed as having the movement blurring removed from the input image. Accordingly, it can be said that

20   processing is performed for movement blurring removal with the signal processing device 4 in Fig. 113.

The processing for movement blurring removal with the signal processing device 4 in Fig. 113 will be described in detail below. First, by modeling (formulating) the

25   mechanism for movement blurring generation, a relation model

is generated which models the relation between the pixel

values of each of the pixels of the input image with

movement blurring and the signal of the actual world 1. The

light signal of the actual world 1 has no movement blurring,

5   and therefore the relation model is a modeling of the

relation between the pixel values of each of the pixels of

the movement blurring image and the pixel values of each of

the pixels of the image with no movement blurring.

Fig. 115 is a diagram describing the light signal of

10   the actual world 1.

The light signal of the actual world 1 is to be

regarded as a waveform $F(x,y)$ on an X - Y plane (a plane

formed of the X direction which is one direction of a

spatial direction, and a Y direction which is perpendicular

15   to the X direction) as illustrated in Fig. 115. The signal

input into the signal processing device 4 of Fig. 113 is

moving in the horizontal direction at the movement amount of

v pixels as described above, and therefore is the same value

as the waveform $F(x,y)$ which is moving at the movement

20   amount of v pixels per shutter time in the same direction as

the spatial direction X. Hereafter, the waveform $F(x,y)$

will be called the light signal function $F(x,y)$.

The actual world estimating unit 15013 of the signal

processing device 4 in Fig. 113 estimates a light signal

25   function $F(x,y)$ of the actual world 1 by finding an

approximation function f(x,y) which approximates the light

signal function F(x,y) of the actual world 1, based on the

input image from the sensor 2.

The input image which is the output of the sensor 2 is

5   the image data configured with multiple pixels wherein the

above-described light signal of the actual world 1 (the

light signal function F(x,y)) is projected as pixel values

from the detecting elements (pixels) of the sensor which has

an integration effect.

10   The integration effect in the case that the sensor 2 is

a CCD will be described with reference to Fig. 116.

As shown in Fig. 116, multiple detecting elements

(pixels) 15031 are disposed on the plane of the sensor 2.

In the example shown in Fig. 116, the direction

15   parallel to 1 predetermined side of the detecting element

15031 is the X direction which is one direction in the

spatial direction, and the direction perpendicular to the X

direction is the Y direction, which is the other direction

in the spatial directions. The direction perpendicular to

20   the X-Y plane is the t direction, which is the time

direction.

Also, with the example in Fig. 116, the spatial shape

of the respective detecting elements 15031 (corresponding to

the pixels of the image data output by the sensor 2) of the

25   sensor 2 is taken as a square of which one side is 1 in

length. The shutter time (exposure time) of the sensor 2 is

taken as 1.

Further, with the example in Fig. 116, the center of

one detecting element 15031 of the sensor 2 is taken as the

5   origin (position x = 0 in the X direction, and position y =

0 in the Y direction) in the spatial direction (X direction

and Y direction), and the intermediate point-in-time of the

exposure time is taken as the origin (position t = 0 in the

t direction) in the temporal direction (t direction).

10   In this case, the detecting element 15031 of which the

center is in the origin (x = 0, y = 0) in the spatial

direction subjects the light signal function F(x, y, t) to

integration with a range between -0.5 and 0.5 in the X

direction, range between -0.5 and 0.5 in the Y direction,

15   and range between -0.5 and 0.5 in the t direction, and

outputs the integral value thereof as a pixel value P.

That is to say, the pixel value P output from the

detecting element 15031 of which the center is in the origin

in the spatial direction is represented with the following

20   Expression (137).

$$P = \int_{-0.5}^{+0.5} \int_{-0.5}^{+0.5} \int_{-0.5}^{+0.5} F(x, y, t)\,dx\,dy\,dt$$

...(137)

The other detecting elements 15031 also output the

pixel value P shown in Expression (137) by taking the center

of the subject detecting element 15031 as the origin in the spatial direction in the same way.

Thus, the input image from the sensor 2 is a collection of data wherein each of the detecting elements (pixels) 15031 has a constant pixel value due to the integration effect of the sensor 2. Also, the integration effect of the sensor 2 comprises the integration of the spatial direction (X-Y direction) of the light signal of the actual world 1 (special mixture) and the integration in the time direction (t direction) (time mixture).

Accordingly, even in the cases wherein movement blurring of an object is occurring in an input image, strictly speaking the pixel value of each of the pixels of the input image is the value generated by both the spatial integration effect and the time integration effect (spatial mixture and time mixture have occurred), but with the movement blurring due to the movement of an object in the horizontal direction, the effect of the time integration effect is great, and therefore with this embodiment, in order to model the generation of movement blurring more easily, let us say that the approximation function $f(x,y)$ is modeled as having generated only the time integration effect by the object moving v pixels per shutter time.

In other words, the approximation function $f(x,y)$ approximating the actual world 1 has no spatial integration

effect, as illustrated in Fig. 117, that is to say, is a
function having a constant value within the various pixels
of the sensor, and let us say that pixel values of the
various pixels of the input image with movement blurring

5 occurring are time-integrated values by the approximation
function f(x,y) in Fig. 117 moving in the horizontal
direction at a constant speed at the movement amount v.

Fig. 118 is a diagram illustrating the relation of the
input image which is input in the signal processing device 4

10 and the processing region which is set in the processing
region setting unit 15011.

The image 15041 (input image) which is input from the
sensor 2 (Fig. 1) into the signal processing device 4 is an
image having a predetermined number of pixels in the spatial

15 direction of the X direction and the spatial direction of
the Y direction.

A region 15042 which is a portion or all of the image
15041 is set as the processing region by the process region
setting unit 15011. The information illustrating the region

20 15042 within the image 15041 is supplied as processing
region information from the processing region setting unit
15011 to the continuity setting unit 15012, the actual world
estimating unit 15013, and the image generating unit 15014.
Hereafter the region 15042 will be called the processing

25 region 15042.

Fig. 119 is a diagram illustrating the processing region 15042.

The processing region 15042 is a region having a processing region width of l = 10 pixels and line number of k = 4, for example, as illustrated in Fig. 119. In other words, in Fig. 119, the processing region 15042 is comprised of 10 x 4 = 40 pixels.

Fig. 120 is a diagram illustrating the approximation function $f(x,y)$ in Fig. 117 at the timing of a predetermined instant regarding one line wherein the value of y is the predetermined value y_c $(y = y_c)$, within the processing region 15042. In other words, Fig. 120 is a diagram illustrating the approximation function $f(x, y_c)$ at the timing of a predetermined instant. This approximation function $f(x, y_c)$ is an approximation function $f(x, y)$ illustrating the relation pixel level and the position of the special direction X when the time direction t and the spatial direction Y is at a fixed value, and this will simply be called an approximation function $f(x)$.

The approximation function in Fig. 120 can be expressed as the following Expression (138).

$$f(x) = \begin{cases} Q_0 & -0.5 \leqq x < 0.5 \\ Q_1 & 0.5 \leqq x < 1.5 \\ Q_2 & 1.5 \leqq x < 2.5 \\ Q_3 & 2.5 \leqq x < 3.5 \\ Q_4 & 3.5 \leqq x < 4.5 \\ Q_5 & 4.5 \leqq x < 5.5 \\ Q_6 & 5.5 \leqq x < 6.5 \\ Q_7 & 6.5 \leqq x < 7.5 \\ Q_8 & 7.5 \leqq x < 8.5 \\ Q_9 & 8.5 \leqq x < 9.5 \end{cases}$$

$$\cdots \quad (138)$$

Expression (138) is an approximation function f(x) at the timing of an instant, and actually, the approximation function f(x) has a movement amount v, and therefore after a 1/v time in Fig. 120, becomes such as that illustrated in Fig. 121. The approximation function in Fig. 120 can be expressed as the following Expression (139).

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$$
f(x) = \begin{cases}
0 & -0.5 \leqq x < 0.5 \\
Q_0 & 0.5 \leqq x < 1.5 \\
Q_1 & 1.5 \leqq x < 2.5 \\
Q_2 & 2.5 \leqq x < 3.5 \\
Q_3 & 3.5 \leqq x < 4.5 \\
Q_4 & 4.5 \leqq x < 5.5 \\
Q_5 & 5.5 \leqq x < 6.5 \\
Q_6 & 6.5 \leqq x < 7.5 \\
Q_7 & 7.5 \leqq x < 8.5 \\
Q_8 & 8.5 \leqq x < 9.5
\end{cases}
$$

$$\dots (139)$$

Further, after a 1/v time in Fig. 121, the function

becomes such as that illustrated in Fig. 122, and the

5 approximation function f(x) at this time is represented with

the following Expression (140).

$$
f(x) = \begin{cases}
0 & -0.5 \leqq x < 0.5 \\
0 & 0.5 \leqq x < 1.5 \\
Q_0 & 1.5 \leqq x < 2.5 \\
Q_1 & 2.5 \leqq x < 3.5 \\
Q_2 & 3.5 \leqq x < 4.5 \\
Q_3 & 4.5 \leqq x < 5.5 \\
Q_4 & 5.5 \leqq x < 6.5 \\
Q_5 & 6.5 \leqq x < 7.5 \\
Q_6 & 7.5 \leqq x < 8.5 \\
Q_7 & 8.5 \leqq x < 9.5
\end{cases}
$$

Here the movement amount v of the object can be
considered as a simplified form as illustrated in Fig. 123,
by the movement of the approximation function f(x)

5   illustrated in Fig. 120 through Fig. 122. In other words,
the object moves instantly to the center of the pixel next
over in the x direction every 1/v time, and stays there for
the period 1/v time. Accordingly, during the 1/v time, the
pixel value of the same value as when the object is not

10   moving as accumulated in the pixels of the sensor. Also,
during the next 1/v time, the pixel values that are the same
as when the object is not moving, is accumulated as to the
pixel that was advanced only one pixel worth in the x
direction.

15   In other words, in the event that the object (the light
signal of the actual world 1) is moving at the movement
amount v, each pixel can be considered to have 1/v times the
pixel value as the same pixel value when the object is not
moving at the movement amount v, accumulated in order, for

20   every 1/v time.

As described above, even if we think of the object as
moving only one pixel worth in the x direction instantly
every 1/v time, the object can be seen as moving at the same
speed in the x direction with the movement amount of v

25   pixels for each unit of time, when viewed at a macro level,

as illustrated by a straight line in Fig. 123.

The accumulation by the detecting elements of the sensor (time integration) of the object having the movement amount v will be further described with reference to Fig.

5   124 through Fig. 126.

Fig. 124 is a diagram showing the approximation function $f(x)$ of $y = y_c$ at a predetermined precise timing, illustrated in Fig. 120, with a X - t plane.

In Fig. 124, the width of the X direction of each pixel

10   15031 is 1, as described in Fig. 116, and the height in the t-direction is the shutter time (=1). Also, the area (the width in the X direction x the height in the t-direction) of each pixel 15031 are each the pixel values Q_0 through Q_9 accumulated (expressed by the total amount of electric

15   charge) in each pixel 15031. These pixel values Q_0 through Q_9 are the pixel values of the image with no movement blurring.

On the other hand, Fig. 125 is a diagram illustrating the pixel values, which are time-integrated and accumulated,

20   when the object is moving at the movement amount v so as to correspond to the pixel values Q_0 through Q_9 in Fig. 124, as P_0 through P_9. In other words this is a diagram of an X-t plane of the pixel values P_0 through P_9 of the input image, regarding one line of the $y = y_c$ within the processing

25   region 15042.

For example, based on the movement of the object described in the above-described Fig. 120 through Fig. 123 with $v = 4$ (pixels), when the pixel values P_0 through P_9 of Fig. 125 are expressed using the pixel values Q_0 through Q_9 in Fig. 124, the result is such as that in Fig. 126.

In other words, for the first $1/v$ time of the shutter time, the pixel values (the electric charge corresponding thereto) equivalent to $1/v$ of the pixel value Q_h ($h = 0$ through 9) with no movement blurring are accumulated into each of the pixels where $x = h$. Then, for the next $1/v$ time, the pixels move over one pixel worth of the movement direction side in the X direction (the pixel on the right side in the diagram), and the pixel values equivalent to $1/v$ of the same pixel value Q_h ($h = 0$ through 8) are accumulated into each of the pixels where $x = h$. Hereafter, similarly, for each $1/v$ time, as the pixels move over one pixel worth of the movement direction side in the X direction, the pixel values equivalent to $1/v$ of the pixel value Q_h ($h = 0$ through 8) are accumulated. Hereafter, as long as the variable h which is a reference numeral has no special restriction, the variable h will express an integer where $h = 0$ through 9.

In other words, with the pixel wherein $X = 0$ is the center thereof (hereafter, this will be called a pixel with $X = 0$), $1/v$ of the pixel value of the pixel value Q_0 (Q_0/v)

is accumulated. With the pixel wherein X = 1 is the center

to the immediate right of the pixel wherein X = 0 (hereafter

this will be called the X = 1 pixel), the pixel value (Q_1/v)

which is 1/v of the pixel value Q_1 and the pixel value (Q_1/v)

5   which is 1/v of the pixel value Q_0 are accumulated. With

the pixel wherein X = 2 is the center to the immediate right

of the pixel wherein X = 1 (hereafter this will be called

the X = 2 pixel), the pixel value (Q_0/v) which is 1/v of the

pixel value Q_0, the pixel value (Q_1/v) which is 1/v of the

10   pixel value Q_1, and the pixel value (Q_2/v) which is 1/v of

the pixel value Q_2 are accumulated. Thereafter, the pixel

values which are 1/v of the pixel values Q_h are similarly

moved over each 1/v time for each pixel, and accumulated.

The following Expression (141) is acquired when

15   expressing the relation illustrated in Figs. 125 and 126

with an expression.

$$(Q_0+Q_1+Q_2+Q_3)\diagup v = P_3$$
$$(Q_1+Q_2+Q_3+Q_4)\diagup v = P_4$$
$$(Q_2+Q_3+Q_4+Q_5)\diagup v = P_5$$
$$(Q_3+Q_4+Q_5+Q_6)\diagup v = P_6$$
$$(Q_4+Q_5+Q_6+Q_7)\diagup v = P_7$$
$$(Q_5+Q_6+Q_7+Q_8)\diagup v = P_8$$
$$(Q_6+Q_7+Q_8+Q_9)\diagup v = P_9$$

... (141)

Here, with the pixels wherein x = 0, 1, or 2, there is

a blank (unknown) region of the accumulated pixel values. Therefore, each of the P_0, P_1, and P_2 has not acquired an accumulated pixel value within the entire shutter time, and so cannot build an expression.

5   Expression (141) is a simultaneous equation wherein the mechanism of movement blurring generation is modeled, with the pixel values of each of the pixels of the movement blurring image being considered to be the accumulated (integrated) value wherein the pixel values of each of the

10   pixels of an image with no movement blurring are accumulated (integrated), while moving at the movement amount v. In Expression (141), the pixel value P_h when the object is moving at the movement amount v is the pixel value already known of the input image to be input into the signal

15   processing device 4, and the pixel values Q_h when the object has no movement expresses the pixel value to be found with no blurring.

Thus, the pixel values P_h when the object is moving at the movement amount v can be said to be the pixel value

20   wherein the pixel values Q_h when the object has no movement are mixed for $1/v$ time each (time mixture). Hereafter, the pixel value P_h when the object is moving at the movement amount v is called the mixed pixel value P_h, and the pixel values Q_h when the object has no movement is simply called

25   the pixel values Q_h.

The approximation function $f(x)$ as an approximation
model wherein the signal of the actual world 1 is modeled is
configured with a value of Q_h, as expressed in Expression
(139) with the above-described example, and so Expression

5   (141) is a model equation as a relation model wherein
relation of the pixel values of each of the pixels of the
movement blurring image as the input image and the signal of
the actual world 1 is modeled. Also, finding the pixel
value Q_h with no movement blurring is the same as finding

10   the approximation function $f(x)$ wherein the actual world
estimating unit 15013 has modeled the signal of the actual
world 1.

The above-described simultaneous equation (141) can be
built by setting the processing region width 1 of the

15   processing region 15042 and the movement amount v. However,
the simultaneous equation (141) only has 7 expressions,
compared to the 10 variables of the pixel values Q_h.
Accordingly, it is difficult to find the pixel values Q_h
with only Expression (141).

20   Therefore, two methods will be described for having at
least the same number of expressions and number of variables.

The first method is a method of hypothesizing that the
edge portions of the processing region is "flat". That is
to say, as shown in Fig. 127, this is a method of

25   hypothesizing that the accumulated pixel value as to the

blank (unknown) region 15051 of the pixel value is the same

as the pixel value (Q_0/v) of $1/v$ of the pixel value Q_0, which

is the edge portion of the first $1/v$ time.

In this case, the following Expression (142) can be

5   newly acquired.

$$(Q_0+Q_0+Q_0+Q_0)/v = P_0$$
$$(Q_0+Q_0+Q_0+Q_1)/v = P_1$$
$$(Q_0+Q_0+Q_1+Q_2)/v = P_2$$

$$\ldots (142)$$

From Expression (141) and Expression (142), the number

of expressions is 10 and the number of variables is 10, and

10   so the pixel value Q_h can be found.

With the processing which is described with reference

to the flowchart in Fig. 114, in the event that there is no

specification (setting) for constraint conditions by the

user, that is to say, in the event that constraint condition

15   information of the equation generating unit 15022 is not

supplied form the user I/F 15016, for example the first

method may be used. However, with the first method, the

edge portions of the processing region are hypothesized as

being "flat", and so the image configured from the pixel

20   value Q_h to be found with the first method can have noise

generated in some cases.

Thus, in the case that constraint condition information

is supplied from the user I/F 15016 to the equation

generating unit 15022, a second method can be applied which is different from the first method. The second method is a method for acquiring a number of expressions greater than the number of variables by combining Expression (141) with

5 an Expression (hereafter referred to as a constraint condition expression), which is built that hypothesizes (constrains) the relation of the pixel values of the adjacent various pixels in the image with no blurring.

In general, an image often has a spatial correlation,

10 and therefore adjacent pixels often do not differ greatly. Thus, for example, a condition (hereafter referred to as a constraint condition) can be hypothesized to say that the difference is 0 (hereafter this will be called "adjacent pixel difference = 0") for the pixel value Q_h between each

15 of the pixels not generating movement blurring. This constraint condition can be expressed with the following Expression (143).

$$Q_{h-1} - Q_h = 0 \qquad h = 1, \cdots, (I-1)$$

$$\cdots (143)$$

20 Also, for example, a condition stating that "the pixel values are changing smoothly" can be hypothesized. This constraint condition can be expressed with the following Expression (144).

$$-Q_{h-1} + 2Q_h - Q_{h+1} = 0 \qquad h = 1, \cdots, (I-2)$$

25 $$\cdots (144)$$

The user viewing an image displayed on the image
display unit 15015 reflecting a blurred object guesses the
original image, that is to say, an image without movement
blurring which is an image of the actual world 1
5   corresponding to the input image, and can set the relation
equation (constraint conditions) between the pixels which
expresses the guessed state, into the equation generating
unit 15022, by operating the user I/F 15016.

With the signal processing device 4 in Fig. 113, the
10   constraint condition of Expression (143) is said to be set
by the user (the constraint condition information is
supplied from the user I/F 15016 which instructs Expression
(143)). In this event, regarding the line illustrated in
Fig. 124, a constraint condition expression can be acquired
15   with is expressed with the following Expression (145).

$$Q_0 - Q_1 = 0$$
$$Q_1 - Q_2 = 0$$
$$Q_2 - Q_3 = 0$$
$$Q_3 - Q_4 = 0$$
$$Q_4 - Q_5 = 0$$
$$Q_5 - Q_6 = 0$$
$$Q_6 - Q_7 = 0$$
$$Q_7 - Q_8 = 0$$
$$Q_8 - Q_9 = 0$$

$$\ldots \quad (145)$$

Expression (145) has 9 expressions, and when added to Expression (141), the number of expressions is 16, and the number of variables Q_h is 10, and so for example, by using the least-square method, a variable Q_h wherein the sum of

5 squares of error generated in the various expressions is the smallest, can be calculated. In other words, the pixel value Q_h with the movement blurring removed (with no movement blurring) may be estimated.

Specifically, if the error generated in each of the

10 expressions in Expression (141) is e_{mi} (i = 3 through 9), and the error generated in each of the expressions in Expression (145) is e_{bj} (b = 0 through 8), Expression (141) and Expression (145) can be expressed by Expression (146) and Expression (147), respectively.

$$(Q_0+Q_1+Q_2+Q_3)/v = P_3+e_{m3}$$
$$(Q_1+Q_2+Q_3+Q_4)/v = P_4+e_{m4}$$
$$(Q_2+Q_3+Q_4+Q_5)/v = P_5+e_{m5}$$
$$(Q_3+Q_4+Q_5+Q_6)/v = P_6+e_{m6}$$
$$(Q_4+Q_5+Q_6+Q_7)/v = P_7+e_{m7}$$
$$(Q_5+Q_6+Q_7+Q_8)/v = P_8+e_{m8}$$
$$(Q_6+Q_7+Q_8+Q_9)/v = P_9+e_{m9}$$

15

$$\ldots \quad (146)$$

$$Q_0 - Q_1 = 0 + e_{b0}$$

$$Q_1 - Q_2 = 0 + e_{b1}$$

$$Q_2 - Q_3 = 0 + e_{b2}$$

$$Q_3 - Q_4 = 0 + e_{b3}$$

$$Q_4 - Q_5 = 0 + e_{b4}$$

$$Q_5 - Q_6 = 0 + e_{b5}$$

$$Q_6 - Q_7 = 0 + e_{b6}$$

$$Q_7 - Q_8 = 0 + e_{b7}$$

$$Q_8 - Q_9 = 0 + e_{b8}$$

$$\ldots \quad (147)$$

From Expression (146) and Expression (147), the following Expression (148) holds.

$$
\left[
\begin{array}{cccccccccc}
1/v & 1/v & 1/v & 1/v & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1/v & 1/v & 1/v & 1/v & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1/v & 1/v & 1/v & 1/v & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1/v & 1/v & 1/v & 1/v & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1/v & 1/v & 1/v & 1/v & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1/v & 1/v & 1/v & 1/v & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1/v & 1/v & 1/v & 1/v \\
\hline
1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1
\end{array}
\right]
\left[
\begin{array}{c}
Q_0 \\ Q_1 \\ Q_2 \\ Q_3 \\ Q_4 \\ Q_5 \\ Q_6 \\ Q_7 \\ Q_8 \\ Q_9
\end{array}
\right]
=
\left[
\begin{array}{c}
P_3 \\ P_4 \\ P_5 \\ P_6 \\ P_7 \\ P_8 \\ P_9 \\
\hline
0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0
\end{array}
\right]
+
\left[
\begin{array}{c}
e_{m3} \\ e_{m4} \\ e_{m5} \\ e_{m6} \\ e_{m7} \\ e_{m8} \\ e_{m9} \\
\hline
e_{b0} \\ e_{b1} \\ e_{b2} \\ e_{b3} \\ e_{b4} \\ e_{b5} \\ e_{b6} \\ e_{b7} \\ e_{b8}
\end{array}
\right]
$$

5

$$\dots (148)$$

Hereafter, as long as the variables i and j have no special restrictions, the variable i will express an integer where i = 3 through 9 and j will express an integer where j

5 = 0 through 8.

Expression (148) is replaced with Expression (149), using a matrix A, and column vectors x, y, and e.

$$Ax = y + e$$

$$\dots (149)$$

10 In this case, the total sum E of the squared errors of the error e_{mi} of Expression (146) and the error e_{bj} of Expression (147) can be expressed with the following expression.

$$E = |e|^2 = \sum e_{mi}^2 + \sum e_{bj}^2$$
$$= (Ax - y)^T (Ax - y)$$
$$= x^T A^T Ax - 2x^T A^T y + y^T y$$

15 $$\dots (150)$$

In order to find the Q_h for which the total sum E of the squared error is the smallest, the fact that the total sum E of the squared error of the equation (150) can have 0 as the value partially differentiated with the column vector x with

20 Q_h as a component leads into the following expression.

$$\frac{\partial E}{\partial x} = 2(A^T Ax - A^T y) = 0$$

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... (151)

From Expression (151), the column vector x (a column
vector x with the pixel value of Q_h as a component) to be
found can be expressed with Expression (152).

$$5 \quad x = (A^T A)^{-1} A^T y$$

... (152)

Now, with Expression (152), the superscript T means
transposing, and the superscript -1 means an inverse matrix.

By substituting the column vector y, of which the mixed
10   image value P_i is a component, into Expression (152) and
computing this, the pixel value Q_h with the movement
blurring removed (with no movement blurring) can be
estimated.

Fig. 128 is a diagram illustrating again the processing
15   region 15042.

A column vector x (= pixel value Q_h) which can be found
from Expression (152) is a column vector x (= pixel value
Q_h) of one line of the y = y_c of the processing region 15042
illustrated in Fig. 128, and therefore in order to estimate
20   a pixel value with no movement blurring for all pixels in
the processing region 15042, the computation of Expression
(152) must be repeated the same number of times k (= 4) as
the line number.

In other words, as with the y = y_c line in the above

description, if the one line which performs processing to find the pixel value Q_h with no movement blurring is called the line of interest, the actual world estimating unit 15013 sets each of all of the lines, in order, as the line of

5 interest, and by performing processing to estimate the pixel values Q_0 through Q_9, which is the approximation function $f(x)$ of the line of interest, an image with no movement blurring can be estimated regarding the processing region 15042 of the input image.

10 Fig. 129 is a configuration example of the inside of the actual world estimating unit 15013 in Fig. 113.

The actual world estimating unit 15013 comprises a model generating unit 15021, an equation generating unit 15022, and an actual world waveform estimating unit 15023.

15 Further, the equation generating unit 15022 comprises a constraint condition setting unit 15061 and a normal equation generating unit 15062.

The movement amount v as the continuity information is supplied to the model generating unit 15021 from the

20 continuity setting unit 15012 as continuity information. The movement amount v in this example expresses that the object is moving in the horizontal direction only v pixels per shutter time, within the processing region of the input image which is set by the processing region setting unit

25 15011, and for example, v = 4, as with the above-described

example. Also, the movement amount v may be a value which
differs for each line, and in the event that the movement
amount v differs for each line, k number, equal to the
number of lines, of the movement amount v is supplied as
5   continuity information from the continuity setting unit
15012 to the model generating unit 15021.

Also, processing region information which specifies the
processing region within the input image is also supplied to
the model generating unit 15021 from the processing region
10   setting unit 15011. In the case of using a processing
region with a rectangular-shaped region as the processing
region, the processing region information can be expressed,
for example, by coordinate values at opposite angles of a
rectangular-shaped processing region as to an absolute
15   coordinates system wherein a predetermined position (pixel)
of the input image is the origin, or the center coordinate
of the processing region and the width (horizontal
direction) and the height (vertical direction) of the
processing region, or the like.

20   The model generating unit 15021 acquires, for example,
a processing region width of 1, and k line numbers, as
illustrated in Fig. 119, from the processing region
information supplied from the processing region setting unit
15011. In this example, let us say that the processing
25   region 15042 is rectangular-shaped, and for example, has 1 =

10 and k = 4. In this case, the processing region width of each line (the number of pixels) are the same, but with the processing region 15042, each line can have a different processing region width. In the case that the processing

5   region width l differs for each line, the model generating unit 15021 acquires a processing region width l of the same number (k) as the number of lines.

Also, the model generating unit 15021 generates an equation (model equation) of a mixed pixel value P_i which is

10   shown in the above-described Expression (141), based on the movement amount v supplied from the continuity setting unit 15012 and the processing region width l and k number of lines acquired from the processing region information, and supplies this to the normal equation generating unit 15062.

15   The constraint condition information specified by the user operating the user I/F 15016 is supplied to the constraint condition setting unit 15061 from the user I/F 15016. For example, the user performs an operation with the user I/F 15016 to select (specify) the desired constraint

20   condition from the constraint conditions which constrain the relation of the pixel values Q_h of each of the pixels of an image with no movement blurring, such as the above-described Expression (143) or Expression (144), which have been set in advance inside the constraint condition setting unit 15061,

25   and the user I/F 15016 supplies the information describing

the selected constraint conditions as the constraint
condition information to the constraint condition setting
unit 15061.

    The constraint condition setting unit 15061 selects a
5   constraint condition expression corresponding to the
constraint condition information supplied from the user I/F
15016 from the constraint condition expressions within the
constraint condition setting unit 15061 itself. Further,
the constraint condition setting unit 15061 acquires the
10 processing region width l based on the processing region
information of the input image supplied from the equation
generating unit 15022 from the processing region setting
unit 15011, and generates only the number, which corresponds
to the processing region width l, of the constraint
15 condition expressions. For example, in the event that
Expression (143) is used which has the condition "adjacent
pixel difference = 0" as the constraint condition
information, the constraint condition setting unit 15061
generates the constraint condition expression expressed by
20 the above-described Expression (145), by acquiring the
processing region width l based on the processing region
information supplied from the processing region setting unit
15011, and supplies this to the normal equation generating
unit 15062. In the example of the processing region 15042
25 illustrated in Fig. 119, the processing region 15042 is

rectangular-shaped, and the processing region width l is the same of each line, but in the case that the processing region width l differs for each line, the number of constraint condition expressions also differ for each line.

5   The equation with k number of mixed pixel value P_i, which is the same as the number of lines, (Expression (141)) from the model generating unit 15021 and the constraint condition Expression (Expression (145)) corresponding to the constraint condition selected by the user operating the user

10   I/F 15016 from the constraint condition setting unit 15061 are supplied to the normal equation generating unit 15062.

First, as illustrated in Fig. 128, the normal equation generating unit 15062 selects a predetermined line from the processing region 15042 as a line of interest. Then the

15   normal equation generating unit 15062 generates a normal equation corresponding to the selected line of interest, which is expressed by Expression (148) (Expression (149)), from a mixed pixel value P_i equation expressed by Expression (141) which is supplied from the model generating unit 15021,

20   and a constraint condition expression expressed by Expression (145) which is supplied from the constraint condition setting unit 15061.

Further, the normal equation generating unit 15062 computes the matrix $(A^T A)^{-1} A^T$, which is a coefficient of the

25   column vector y of the right side of Expression (152), and

substitutes the mixed pixel value P_i which is acquired based on the input image supplied from the sensor 2 (Fig. 1) into the column vector y. The matrix $(A^TA)^{-1}A^T$ is computed, and Expression (152) into which the mixed pixel value Pi is

5   substituted is further supplied from the normal equation generating unit 15062 to the actual world waveform estimating unit 15023.

When the normal equation generating unit 15062 finishes the above-described generation of the normal equation, the

10 computation of the matrix $(A^TA)^{-1}A^T$, and the processing such as the substitution of the mixed pixel value P_i, a line not yet selected is selected as the next line of interest, and similar processing is performed as to the selected next line of interest.

15   The actual world waveform estimating unit 15023, by computing Expression (152) which is supplied from the normal equation generating unit 15062, finds the column vector x, that is to say, the pixel value Q_h with no movement blurring (approximation function), and supplies this to the image

20 generating unit 15014 (Fig. 113).

The image generating unit 15014 replaces a portion of the processing region 15042 of the input image with the image of the pixel value Q_h with no movement blurring, which is supplied from the actual world waveform estimating unit

25 15023, based on the processing region information supplied

from the processing region setting unit 15011, and generates
this as an output image, and supplies this to the image
display unit 15015.

Next, the actual world estimating processing of the
actual world estimating unit 15013 in step S15008 in Fig.
114 will be described inn detail with reference to the
flowchart in Fig. 130.

First, in step S15031, the model generating unit 15021
acquires the processing region width 1 and the number of
lines k, based on the processing region information supplied
from the processing region setting unit 15011, and the flow
proceeds to step S15032.

In step S15032, the model generating unit 15021
acquires the movement amount v, which is equivalent to the
number of lines k in the processing region 15042, from the
continuity setting unit 15012, and the flow proceeds to step
S15033.

In step S15033, the model generating unit 15021
generates an equation for the mixed pixel value P_i for each
line, and the flow proceeds to step S15034. In other words,
the model generating unit 15021 generates k number of model
equations (expressions (141)).

In step S15034, the constraint condition setting unit
15061 selects the constraint condition expression
corresponding to the constraint condition information

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supplied from the user I/F 15016, from the constraint
condition expressions existing within the constraint
condition setting unit itself. Also, the constraint
condition setting unit 15061 acquires the processing region
width l from the processing region information of the input
image which is supplied from the equation generating unit
15022 from the processing region setting unit 15011, and
generates an constraint condition Expression (Expression
(145)) corresponding to the constraint condition information
from the users interface 15016, which comprises a number of
equations corresponding to the processing region width l,
and the flow proceeds to step S15035.

In step S15035, the normal equation generating unit
15062 selects one predetermined line as the line of interest
from the processing region 15042, and the flow proceeds to
step S15036.

In step S15036, the normal equation generating unit
15062 generates a normal equation expressed by Expression
(148) (Expression (149)) from the equation (model equation)
of the mixed pixel value P_i expressed by Expression (141)
which is supplied from the model generating unit 15021, and
the equation (constraint condition expression) of the
constraint condition expressed by Expression (145) which is
supplied from the constraint condition setting unit 15061,
and the flow proceeds to step S15037.

In step S15037, the normal equation generating unit 15062 computes the matrix $(A^TA)^{-1}A^T$, which is a coefficient of the column vector y of the right side of Expression (152), and the flow proceeds to step S15038.

In step S15038, the normal equation generating unit 15062 substitutes the mixed pixel value P_i which is acquired based on the input image supplied from the sensor 2 (Fig. 1) into the column vector y, and the flow proceeds to step S15039.

In step S15039, the actual world waveform estimating unit 15023 computes a normal equation. That is to say, the actual world waveform estimating unit 15023 find a pixel value Q_h with no movement blurring by computing Expression (152) which is supplied from the normal equation generating unit 15062, and the flow proceeds to step S15040.

In step S15040, determination is made as to whether or not processing is performed to find a pixel value Q_h with no movement blurring as to all lines of the processing region 15042. In the event that it is determined that processing is not performed to find a pixel value Q_h with no movement blurring as to all lines of the processing region 15042, the process is returned to step S15035, and the processing in steps S15035 through S15040 is repeated. That is to say, a line not yet selected of the processing region 15042 is selected as the next line of interest, and processing is

performed to find a pixel value Q_h with no movement blurring.

On the other hand, in the event that it is determined that processing is performed to find a pixel value Q_h with no movement blurring as to all lines of the processing

5   region 15042, the actual world estimating processing ends and returns.

Thus, by generating a normal equation (Expression (148)) as to one line which is the line of interest of the processing region 15042, and repeating the processing to

10   find a pixel value Q_h with no movement blurring k number of times, which is the number of lines in the processing region 15042, the pixel value Q_h with no movement blurring can be found across the entire region of the processing region 15042.

15   In the event that the movement amount v and the processing region width l are each the same for each line of the processing region 15042, the matrix A in Expression (148) is the same for every line. Accordingly, the matrix $(A^T A)^{-1} A^T$ in Expression (148) also is the same for every line,

20   and the processing to compute the matrix $(A^T A)^{-1} A^T$ for each line can be omitted.

Next, the actual world estimating processing of the actual world estimating unit 15013 in step S15008 in Fig. 114 in the event that the movement amount v and the

25   processing region width l are each the same for each line of

the processing region 15042 will be described with reference
to the flowchart of Fig. 131. However, the portions in Fig.
131 which are similar to the flowchart in Fig. 130 will omit
the description thereof as appropriate.

5   In Fig. 131, the processing in step S15057 which
corresponds to step S15035 in Fig. 130 is positioned not
between step S15054 and S15055, but between steps S15056 and
S15058. Further, in step S15060, if it is determined that
processing is not performed to find a pixel value Q_h with no
10   movement blurring as to all lines of the processing region
15042, the process is returned to step S15057.

In other words, in the event that the movement amount v
and the processing region width l of each line of the
processing region 15042 are each the same, the normal
15   equation generated in step S15055 is the same for each line,
and therefore, after computing the matrix $(A^TA)^{-1}A^T$ as to the
first line of interest in step S15056, computing the matrix
$(A^TA)^{-1}A^T$ as to the remaining lines of interest (the
processing in step S15056) is not necessary. Accordingly,
20   the selection of the line of interest (step S15057), the
substitution of the mixed pixel value P_i (the processing in
step S15058), and the computation of the normal equation
(the processing in step S15059) only need be executed in
order, as to the lines not selected in the processing region
25   15042.

Thus, with the embodiment illustrated in Fig. 113, a normal equation is generated from an equation of the mixed pixel value P_i wherein a pixel value generating movement blurring is modeled with a pixel value with no movement

5   blurring (model equation), and a constraint condition expression using the relation between adjacent pixels of a pixel value with no movement blurring, and by computing this normal equation, a pixel value with no movement blurring (approximation function) is found, and therefore an image

10 with good image quality can be generated.

Figs. 132 through 134 are diagrams to describe the processing results by the signal processing device 4 in Fig. 113.

Fig. 132 illustrates an input image to be input in the

15 signal processing device 4 in Fig. 113. With the input image in Fig. 132, the characters "TAL" are moving in the direction from left to right at the same speed, and movement blurring is occurring in the horizontal direction.

Fig. 133 is an image using the above-described first

20 method, that is to say, a expression hypothesizing that the edge portion of the processing region is flat is added to the model equation from the input image in Fig. 132 and a normal equation is generated, and the image in Fig. 133 is generated by computing the normal equation. As is clear by

25 comparing Fig. 132 and Fig. 133, in the image in Fig. 133,

the movement blurring occurring in the input image in Fig. 132 is reduced, and the characters "TAL" are relatively clearly displayed.

On the other hand, Fig. 134 is an image using the above-described second method, that is to say, a normal equation is generated by adding a conditional expression constraining the relation of the adjacent pixel values from the input image in Fig. 132 to the model equation, and the image in Fig. 134 is generated by computing the normal equation. In the image in Fig. 134 also, the movement blurring occurring in the input image in Fig. 132 is reduced, and the characters "TAL" are clearly displayed.

With the embodiments in Figs. 132 through 134, the image in Fig. 134 by the second method is an image with has less noise and no movement blurring as compared to the image in Fig. 133 by the first method.

In the above example, the constraint condition information supplied from the user I/F 15016 to the constraint condition setting unit 15061 is said to be information expressing which constraint condition the user has selected (specified) from the several constraint conditions which are set in advance internally in the constraint condition setting unit 15061, but it can be such that the user can directly input the constraint condition expression by operating the user I/F 15016.

With the embodiment of the signal processing device 4 illustrated in Fig. 113, an image with no movement blurring is generated such that the total sum E of the squared error expressed with Expression (150) becomes as small as possible,

5   that is to say, generated such that the error occurring in the equation of the mixed pixel value P_i and the error occurring in the constraint condition expression becomes as small as possible. Corresponding thereto, for example, of the error e_{mi} occurring in the equation of the mixed pixel

10   value P_i of Expression (146) and the error e_{bj} occurring in the constraint condition expression of Expression (147), one error or the other can be made as small as possible, and thus the balance (weighting) of the model equation and the constraint condition expression can be adjusted and thus

15   generate an image with no movement blurring.

Fig. 135 illustrates such a configuration example of the embodiment of the signal processing device 4, which generates an image with no movement blurring by adjusting the weighting of the equation of the mixed pixel value P_i

20   (the model equation) and the equation of the constraint conditions (constraint condition expression).

In other words, Fig. 135 illustrates a configuration example of another embodiment of the application example of the signal processing device 4 illustrated in Fig. 111.

25   An image of one frame or one field, for example, as the

data 3 of the sensor 2 is input into the signal processing
device 4 in Fig. 135. Here, let us say that an object
having a predetermined shape which moves at a fixed speed of
v pixels per shutter time (exposure time) in the horizontal
5 direction (sideways direction) of the image is displayed in
the input image. That is to say, the object is moving at
the movement amount of v pixels in the horizontal direction,
and therefore the light signal of the object and the light
signal of the portions other than the object are mixed (time
10 mixture) by the time-integration effect of the sensor 2, and
thus, the input image becomes a blurred image in portions
such as the edge portions of the object. The signal
processing device 4 shown in Fig. 135 generates high-quality
output images wherein movement blurring occurring due to
15 such temporal mixing has been removed from the input image.

In Fig. 135, the processing region setting unit 15081,
the continuity setting unit 15082, the actual world
estimating unit 15083, image generating unit 15084, image
display unit 15085, and user I/F 15086, each correspond to
20 the processing region setting unit 10001, the continuity
setting unit 10002, the actual world estimating unit 10003,
image generating unit 10004, image display unit 10005, and
user I/F 10006 shown in Fig. 111, and basically perform the
same processing as the processing region setting unit 10001,
25 the continuity setting unit 10002, the actual world

estimating unit 10003, image generating unit 10004, image
display unit 10005, and user I/F 10006. Further, in Fig.
135, the actual world estimating unit 15083 comprises a
model generating unit 15091, an equation generating unit

5   15092, and actual world waveform estimating unit 15093. The
model generating unit 15091, equation generating unit 15092,
and actual world waveform estimating unit 15093 correspond
to each of the model generating unit 10011, equation
generating unit 10012, and actual world waveform estimating

10 unit 10013 in Fig. 111, and basically perform the same
functions as each of the model generating unit 10011,
equation generating unit 10012, and actual world waveform
estimating unit 10013.

Note however, that in Fig. 135, the assisting

15 information which the user I/F 15086 outputs by the user
operating the user I/F 15086, is supplied to the equation
generating unit 15092.

In other words, in Fig. 135, by operating the user I/F
15086, with the equation generating unit 15092, the user can

20 set the constraint conditions which constrain the relation
between each of the pixels of an image with no movement
blurring, which is an image of the actual world 1
corresponding to the input image, and when the user performs
an operation to set the constraint conditions, the user I/F

25 15086 supplies the constraint condition information

expressing the constraint conditions set by the operation to the equation generating unit 15092.

Specifically, for example, a user who views an image reflecting a blurring image displayed on the image display unit 15085 guesses the original image, that is to say, an image without movement blurring which is an image of the actual world 1 corresponding to the input image. Also, for example, the user guesses predetermined regions where blurring is occurring as the edge portions, and guesses the relation of the pixel values between each of the pixels (the constraint conditions), such as the difference being large between the pixel values (level) between the adjacent pixels at the edge portions. Further, the user can set the conditions suitable for the guessed relation of the pixels value between each of the pixels into the equation generating unit 15092, by operating the user I/F 15086.

Also, in Fig. 135, the processing region information, which is supplied from the processing region setting unit 15081 to the actual world estimating unit 15083, is supplied to the model generating unit 15091 and the equation generating unit 15092 of the actual world estimating unit 15083. The model generating unit 15091 and the equation generating unit 15092 recognize the processing region in the input image from the processing region information which is supplied from the processing region setting unit 15081.

The continuity setting unit 15082 sets a movement amount (movement vector) v in the input image as the continuity information that an object is moving in the horizontal direction of the image at the constant speed of v
5   pixels per shutter time, and supplies this movement amount v as the continuity information to the model generating unit 15091 of the actual world estimating unit 15083.

The model generating unit 15091 generates an equation (hereafter referred to as model equation as appropriate) as
10   a model (hereafter referred to as relation model as appropriate), wherein the relation between the signal of the actual world 1 and the pixel values of each of the pixels of the movement blurring image as the input image which considers the movement amount v as the continuity
15   information supplied from the continuity setting unit 15082, regarding the processing region recognized by the processing region information which is supplied from the processing region setting unit 15081, and supplies the generated model equation to the equation generating unit 15092.

20   The equation generating unit 15092 generates a constraint condition Expression (hereafter referred to as constraint condition expression as appropriate), based on the constraint condition information supplied from the user I/F 15086.   Also, the equation generating unit 15092 sets
25   the weighting into the constraint condition expression for

adjusting the balance of the model equation supplied from

the model generating unit 15091, and substitutes the pixel

values of each of the pixels of the input image comprising

the processing region into the equation formed from the

5   weighted constraint condition expression and the model

equation, and thus, generates an equation to find the

approximation function as a model (hereafter referred to as

approximation model) wherein the signal of the actual world

1 is modeled, and supplies this to the actual world waveform

10   estimating unit 15093.

The actual world waveform estimating unit 15093

estimates the waveform of the signal of the actual world 1

by computing the equation supplied from the equation

generating unit 15092. In other words, the actual world

15   waveform estimating unit 15093 finds the approximation

function as an approximation model, and supplies the

approximation function to the image generating unit 15084 as

the estimation result of the signal waveform of the actual

world 1. Note that approximation function approximating the

20   actual world 1 signals include functions with constant

function values, regardless of argument value.

The image generating unit 15084 recognizes the

processing region in the input image from the processing

region information supplied from the processing regions

25   setting unit 15081. Also, the image generating unit 15084

generates a signal more closely approximating the signal of the actual world 1, from the approximation function supplied from the actual world waveform estimating unit 15093, that is to say, generates an image with no movement blurring, and

5   replaces the image of the processing region of the input image with an output image wherein the image has no movement blurring, generates this as an output image, and supplies this to the image display unit 15085.

Next, the processing of the signal processing device 4

10 in Fig. 135 will be described with reference to the flowchart in Fig. 136.

First, in step S15081, the signal processing device 4 performs pre-processing, and the flow proceeds to step S15082. That is to say, the signal processing device 4

15 supplies one frame or one field, for example, of the input image, supplied from the sensor 2 (Fig. 1) as data 3, to the processing region setting unit 15081, continuity setting unit 15082, actual world estimating unit 15083, image generating unit 15084, and image display unit 15085.

20 Further, the signal processing unit 4 causes the image display unit 15085 to display the input image.

In step S15082, the user I/F 15086 determines whether or not there has been some sort of user input, by the user operating the user I/F 15086. In step S15082, in the event

25 that determination is made that there is no user input, i.e.,

in the event that the user has made no operations, the flow
skips steps S15083 through S15085, and proceeds to step
S15086.

On the other hand, in the event that determination is
5   made in step S15082 that there has been user input, i.e., in
the event that the user has viewed the input image displayed
on the image display unit 15085 and operated the user I/F
15086, thereby making user input indicating some sort of
instruction or information, the flow proceeds to step S15083,
10 where the user I/F 15086 determines whether or not the user
input is ending instructions for instructing ending of the
processing of the signal processing device 4.

In the event that determination is made in step S15083
that the user input is ending instructions, the signal
15 processing device 4 ends processing.

On the other hand, in the event that determination is
made in step S15083 that the user input is not ending
instructions, the flow proceeds to step S15084, where the
user I/F 15086 determines whether or not the user input is
20 constraint condition information. In the event that
determination is made in step S15084 that the user input is
not constraint condition information, the flow skips step
S15085, and proceeds to step S15086.

Also, in step S15084, in the event that the user input
25 is determined to be constraint condition information, the

flow proceeds to step S15085, and the user I/F 15086

supplies the constraint condition information to the

equation generating unit 15092, and the flow proceeds to

step S15086.

5   In step S15086, the processing region setting unit

15081 sets the processing region based on the input image,

and supplies the processing region information identifying

the processing region to the continuity setting unit 15082,

model generating unit 15091 and equation generating unit

10   15092 of actual world estimating unit 15083, and image

generating unit 15084, and the flow proceeds to step S15087.

Here, in the setting of processing region in step S15086 the

user inputs the processing region instruction information by

operating the user I/F 15086, and this can be performed

15   based on the processing region instruction information, or

it can be performed without processing region instruction

information from the user.

In step S15087, the continuity setting unit 15082

recognizes the processing region in the input image, from

20   the processing region information supplied from the

processing region setting unit 15081. Further, the

continuity setting unit 15082 sets the continuity of the

actual world 1 signals lost from one portion of the

continuity in the image data at that processing region, and

25   supplies continuity information representing that continuity

to the model generating unit 15091 of the actual world

estimating unit 15083 and the flow proceeds to step S15088.

Here the continuity setting unit 15082 sets the

movement amount v, expressing that the movement is in the

5   horizontal direction at a constant speed of v pixels per

shutter time (exposure time), as the continuity information,

and supplies this to the model generating unit 15091 of the

actual world estimating unit 15083. The continuity setting

unit 15082 sets the movement amount showing only the

10   movement size as continuity information, under the premise

that the object is moving in a horizontal direction, but a

movement vector showing the size and direction of the

movement of the object can be set as continuity information

as well. The setting of continuity in step S15087 can be

15   arranged by the user inputting the continuity instruction

information by operating the user I/F 15086, and can be

performed based on this continuity instruction information,

or can be performed with no continuity instruction

information from the user.

20   The actual world estimating unit 15083 performs actual

world estimating processing in step S15008. In other words,

with the actual world estimating unit 15083, the model

generating unit 15091 generates an equation (model equation)

as the model (relation model) wherein the relation of the

25   pixel values of each of the pixels of the input image which

has movement blurring and the signal of the actual world 1 is modeled, based on the movement amount v supplied from the continuity setting unit 15082 in step S15087 and the processing region information supplied from the processing

5   region setting unit 15081 in step S15086, and the generated model equation is supplied to the equation generating unit 15092.

The equation generating unit 15092 generates a constraint condition expression based on the constraint

10   condition information supplied from the user I/F 15086 in step S15085, and sets the weighting for adjusting the balance with the model equation in the generated constraint condition expression. Also, the equation generating unit 15092 generates an equation for finding the approximation

15   function as the model (approximation model) wherein the signal of the actual world 1 is modeled, from the weighted constraint condition expression and the model equation supplied from the model generating unit 15091 to the equation generating unit 15092, and substitutes the pixel

20   values of each of the pixels of the input image into this equation, and supplies this to the actual world waveform estimating unit 15093. In the event that the user has not specified (set) constraint condition information, that is to say, in the event that NO is determined to be the case in

25   step S15082 or S15084, the equation generating unit 15092

performs predetermined processing such as a method for

solving a simultaneous equation formed of a model equation

and an equation hypothesizing that the edge portions of the

processing region is "flat", as described in the embodiment

5   in Fig. 113, for example.

Now, the weighting can be set for the constraint

condition expression only, for the model equation only, or

for both the constraint condition expression and the model

equation.

10   The actual world waveform estimating unit 15093

estimates the waveform of the actual world 1 signal, that is

to say, finds the approximation function as a model wherein

the actual world 1 signal is modeled, by computing the

equation supplied from the equation generating unit 15092,

15   and the approximation function is supplied to the image

generating unit 15084 as the estimation result of the signal

waveform of the actual world 1.

The details of the actual world estimating process of

step S15088 will be described later with reference to Fig.

20   138.

After the processing in step S15088, the flow proceeds

to step S15089, and the image generating unit 15084

generates a signal more closely approximating the signal of

the actual world 1, from the approximation function supplied

25   from the actual world waveform estimating unit 15093, that

is to say, generates an image with no movement blurring, and based on the processing region information supplied from the processing region setting unit 15081, converts the portion of the processing region of the input image into an image

5   which has no movement blurring generated, generates this as an output image, and supplies this to the image display unit 15085, and the flow proceeds to step S15090.

In step S15090, the image display unit 15085 displays the output image supplied from the image generating unit

10   15084 instead of the input image displayed in step S15081, or along with the input image, and the flow proceeds to step S15091.

In step S15091, as with the case of step S15082, the user I/F 15086 determines whether or not there has been some

15   sort of user input by the user operating the user I/F 15086, and in the event that determination is made that there has been no user input, i.e., in the event that the user has made no operations, the flow returns to step S15091, and awaits some sort of user input.

20   Also, in the event that determination is made in step S15091 that there has been user input, i.e., in the event that the user has viewed the input image or output image displayed on the image display unit 15085 and operated the user I/F 15086, thereby making user input representing some

25   sort of instructions or information, the flow proceeds to

step S15092, where the user I/F 15086 determines whether or not the user input is ending instructions instructing ending of the processing of the signal processing device 4.

In the event that determination is made in step S15092
that the user input is ending instructions, the signal processing device 4 ends processing.

On the other hand, in the event that determination is made in step S15092 that the user input is not ending instructions, the flow proceeds to step S15093, where the user I/F 15086 determines whether or not the user input is constraint condition information. In the event that determination is made in step S15093 that the user input is not constraint condition information, the flow returns to step S15091, and the same processing is repeated thereafter.

Also, in step S15093, in the event that determination is made that the user input is constraint condition information, the flow returns to step S15085, and as described above, the user I/F 15086 supplies the constraint condition information to equation generating unit 15092.
The flow then proceeds from step S15085 to step S15086, and hereafter the same processing is repeated. Now, in the event that the signal processing device 4 repeats the processing of step S15085 through step S15093, the processing of the above-described step S15086 and S15087 are the same as that set by the first processing S15086 and

S15087, and the same process as the first process may be repeated, or may be skipped.

Thus, with the signal processing device 4 in Fig. 135, by finding an approximation function of a model wherein the signal of the actual world 1 is modeled, an output image of high image quality with no movement blurring can be generated.

Also, by operating the user I/F 15086, the user can set constraint conditions which constrain the relation between each of the pixels in the original image having no movement blurring, and in the event that a new constraint condition is input, an image without movement blurring can be obtained again, and therefore an output image of high image quality according to the preference of the user can be easily acquired.

In the signal processing device 4 in Fig. 135, an output image without movement blurring is generated by finding an approximation function which approximates the light signal of the actual world 1, but this output image can be regarded as having the movement blurring removed from the input image. Accordingly, it can be said that processing is performed for movement blurring removal with the signal processing device 4 in Fig. 135.

Next, the internal configuration of the actual world estimating unit 15083 in Fig. 135 will be described with

reference to Fig. 137. With the embodiment in Fig. 135 also, the mechanism for generating movement blurring of objects reflecting in the input image is modeled as a relation of the above-described Expression (141), which is an example

5   shown in Figs. 125 and 126.

In other words, the pixel values of each of the pixels of the movement blurring image as the input image are values wherein the pixel values (or the electric charge corresponding thereto) of each of the pixels of an image

10   with no movement blurring which accumulate (integrate) while moving at the movement amount v, and models the mechanism for movement blurring generating.

The actual world estimating unit 15083 comprises a model generating unit 15091, an equation generating unit

15   15092, and an actual world waveform estimating unit 15093. Further, the equation generating unit 15092 comprises a constraint condition setting unit 15101, a weighting changing unit 15012, and a normal equation generating unit 15103.

20   The movement amount v as the continuity information is supplied to the model generating unit 15091 by the continuity setting unit 15082. The movement amount v in this example expresses the continuity of the object moving in the horizontal direction at a constant speed of v pixels

25   per shutter time, within the processing region of the input

image which is set in the processing region setting unit 15081, and for example, v = 4, as with the above-described example. Also, the movement amount v may be a value which differs for each line, and in the event that the movement

5 amount v differs for each line, k number, equal to the number of lines, of the movement amount v is supplied as continuity information from the continuity setting unit 15082 to the model generating unit 15091.

Also, processing region information which specifies the

10 processing region within the input image is also supplied to the model generating unit 15091 from the processing region setting unit 15081. In the case of using a rectangular-shaped region as the processing region, the processing region information can be expressed, for example, by

15 coordinate values at opposite angles of a rectangular-shaped processing region as to an absolute coordinates system wherein a predetermined position (pixel) of the input image is the origin, or the center coordinate of the processing region and the width (horizontal direction) and the height

20 (vertical direction) of the processing region.

The model generating unit 15091 acquires, for example, a processing region width of l, and k line numbers, as illustrated in Fig. 119, from the processing region information supplied from the processing region setting unit

25 15081. In this example, let us say that the processing

region 15042 is rectangular-shaped, and for example, has l = 10 and k = 4. In this case, the processing region width of each line (the number of pixels) are the same, but with the processing region 15042, each line may have a different

5 processing region width. In the case that the processing region width l differs for each line, the model generating unit 15091 acquires a processing region width l of the same number (k) as the number of lines.

Also, the model generating unit 15091 generates an

10 equation (model equation) of a mixed pixel value P_i which is shown in the above-described Expression (141), based on the movement amount v supplied from the continuity setting unit 15012 and the processing region width l and k number of lines acquired from the processing region information, and

15 supplies this to the normal equation generating unit 15103.

The constraint condition information specified by the user operating the user I/F 15086 is supplied to the constraint condition setting unit 15101 from the user I/F 15086. For example, the user performs an operation with the

20 user I/F 15086 to select (specify) the desired constraint condition from the constraint conditions which constrain the relation of the pixel values Q_h of each of the pixels of an image with no movement blurring, such as the above-described Expression (143) or Expression (144), which have been set in

25 advance inside the constraint condition setting unit 15101,

and the user I/F 15086 supplies the information describing the selected constraint conditions as the constraint condition information to the constraint condition setting unit 15101.

5   The constraint condition setting unit 15101 selects a constraint condition expression corresponding to the constraint condition information supplied from the user I/F 15086 from the constraint condition expressions within the constraint condition setting unit 15101 itself. Further,

10   the constraint condition setting unit 15101 acquires the processing region width l based on the processing region information of the input image supplied from the equation generating unit 15092 from the processing region setting unit 15081, and generates only the number which corresponds

15   to the processing region width l, for the constraint condition expressions. For example, in the event that Expression (143) is used which has the condition "adjacent pixel difference = 0" as the constraint condition information, the constraint condition setting unit 15101

20   generates the constraint condition expression expressed by the above-described Expression (145), by acquiring the processing region width l based on the processing region information supplied from the processing region setting unit 15081, and supplies this to the normal equation generating

25   unit 15103. In the example of the processing region 15042

illustrated in Fig. 119, the processing region 15042 is rectangular-shaped, and the processing region width l is the same of each line, but in the case that the processing region width l differs for each line, the number of

5   constraint condition expressions also differ for each line.

A weighting W_m as to the model equation and a weighting W_b as to the constraint condition expression are set in advance in the weighting changing unit 15102. With this embodiment, the weighting coefficient W relating to the

10   constraint condition expression is set by Expression (153), and using only the weighting relating to the constraint condition expression, the balance of the model equation and the constraint condition expression is adjusted.

$$W = W_b / W_m$$

15   ... (153)

The weighting changing unit 15102 changes the weighting of the model equation and the constraint condition expression in the normal equation generated by the normal equation generating unit 15103, by supplying the weighting

20   coefficient W to the normal equation generating unit 15103.

The mixed pixel value P_i equation with the same number of k as the line numbers from the model generating unit 15091 (Expression (141)) and the constraint condition Expression (Expression (145)) corresponding to the

25   constraint conditions selected from the constraint condition

setting unit 15101 by the user operating the user I/F 15086

are supplied to the normal equation generating unit 15103.

   With the normal equation generating unit 15103, the

weighting coefficient W is set by the weighting changing

5   unit 15102, regarding Expression (147) wherein the error e_{bj}

is considered in the constraint condition Expression (145)

which is supplied from the constraint condition setting unit

15101 (the weighting W as to the model equation and

constraint condition [equation?] which was 1:1 is changed).

10   In other words, Expression (147) is changed into the

following Expression (154) of which both sides are

multiplied by the weighting W. Here, the weighting

coefficient W is for example a predetermined value such as

0.1. In this case, a pixel value Q_h, which makes the error

15   e_{mi} of the model equation smaller than the error e_{bj} of the

constraint condition expression, is found.

$$W(Q_0 - Q_1) = We_{b0}$$
$$W(Q_1 - Q_2) = We_{b1}$$
$$W(Q_2 - Q_3) = We_{b2}$$
$$W(Q_3 - Q_4) = We_{b3}$$
$$W(Q_4 - Q_5) = We_{b4}$$
$$W(Q_5 - Q_6) = We_{b5}$$
$$W(Q_6 - Q_7) = We_{b6}$$
$$W(Q_7 - Q_8) = We_{b7}$$
$$W(Q_8 - Q_9) = We_{b8}$$

$$\ldots \ (154)$$

The normal equation generating unit 15103 selects one

predetermined line as the line of interest from the

processing region 15042 as shown in Fig. 128. Then, the

5 normal equation generating unit 15103 generates the normal

equation expressed by the following Expression (155), from

the mixed pixel value P_i equation (model equation) expressed

by Expression (141) which is supplied from the model

generating unit 15091 corresponding to the selected line of

10 interest, and the constraint condition expression expressed

by Expression (154) wherein the weighting coefficient W is

added to Expression (145) which is supplied from the

constraint condition setting unit 15101.

$$
\begin{bmatrix}
1/v & 1/v & 1/v & 1/v & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1/v & 1/v & 1/v & 1/v & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1/v & 1/v & 1/v & 1/v & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1/v & 1/v & 1/v & 1/v & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1/v & 1/v & 1/v & 1/v & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1/v & 1/v & 1/v & 1/v & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1/v & 1/v & 1/v & 1/v \\
W & -W & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & W & -W & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & W & -W & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & W & -W & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & W & -W & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & W & -W & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & W & -W & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & W & -W & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & W & -W
\end{bmatrix}
\begin{bmatrix}
Q_0 \\ Q_1 \\ Q_2 \\ Q_3 \\ Q_4 \\ Q_5 \\ Q_6 \\ Q_7 \\ Q_8 \\ Q_9
\end{bmatrix}
=
\begin{bmatrix}
P_3 \\ P_4 \\ P_5 \\ P_6 \\ P_7 \\ P_8 \\ P_9 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0
\end{bmatrix}
+
\begin{bmatrix}
e_{m3} \\ e_{m4} \\ e_{m5} \\ e_{m6} \\ e_{m7} \\ e_{m8} \\ e_{m9} \\ We_{b0} \\ We_{b1} \\ We_{b2} \\ We_{b3} \\ We_{b4} \\ We_{b5} \\ We_{b6} \\ We_{b7} \\ We_{b8}
\end{bmatrix}
$$

$$\dots \ (155)$$

e_{mi} is the error occurring in each expression in Expression (141), and e_{bj} is the error occurring in each

5 expression in Expression (154).

Here, Expression (155) will be replaced by Expression (156), using the matrix A' and the column vectors x, y, and e'.

$$A'x = y + e'$$

10 $\dots \ (156)$

In this case, the total sum E' of the squared error of the error e_{mi} of Expression (146) and the error e_{bj} of Expression (154) can be expressed with the following

expression.

$$E' = \sum e_{mi}^2 + W^2 \sum e_{bj}^2$$

... (157)

In order to find the Q_h for which the total sum E of the

5   squared error is the smallest, the column vector x (the

column vector x with the pixel value Q_h as a component) can

be expressed by Expression (158), from the equation similar

to the above-described equations (150) and (151).

$$x = (A'^T A')^{-1} A'^T y$$

10   ... (158)

Now, with Expression (158), the superscript T means

transposing, and the superscript -1 means an inverse matrix.

With Expression (157), when the weighting coefficient W

is small, a sharp image can be found which can better

15   satisfy Expression (141) even with some noise allowed, and

on the other hand, when the weighting coefficient W is large,

an image which is flat with little noise that can satisfy

Expression (145), rather than Expression (141), can be found.

That is to say, by adjusting the value of the weighting

20   coefficient W, the balance of "sharpness" and "noise" can be

adjusted.

The normal equation generating unit 15103 computes the

matrix $(A'^T A')^{-1} A'^T$, which is a coefficient of the column

vector y of the right side of Expression (158), and

substitutes the mixed pixel value P_i which is acquired based

on the input image supplied from the sensor 2 (Fig. 1) into

the column vector y. The matrix $(A'^T A')^{-1} A'^T$ is computed,

5   and Expression (158) into which the mixed pixel value Pi is

substituted is further supplied from the normal equation

generating unit 15103 to the actual world waveform

estimating unit 15093.

When the normal equation generating unit 15103 finishes

10 the above-described generation of the normal equation, the

computation of the matrix $(A'^T A')^{-1} A'^T$, and the processing

such as the substitution of the mixed pixel value P_i

regarding the selected line of interest, a line not yet

selected is selected as the next line of interest, and

15 similar processing is performed as to the selected next line

of interest.

The actual world waveform estimating unit 15093, by

computing Expression (158) which is supplied from the normal

equation generating unit 15103, finds the column vector x,

20 that is to say, the pixel value Q_h with no movement blurring,

and supplies this to the image generating unit 15084 (Fig.

135).

The image generating unit 15084 replaces a portion of

the processing region 15042 of the input image with the

25 image of the pixel value Q_h with no movement blurring, which

is supplied from the actual world waveform estimating unit

15093, based on the processing region information supplied

from the processing region setting unit 15081, and generates

this as an output image, and supplies this to the image

5   display unit 15085.

Next, the actual world estimating processing of the

actual world estimating unit 15083 in step S15088 in Fig.

136 will be described with reference to the flowchart in Fig.

138.

10   First, in step S15101, the model generating unit 15091

acquires the processing region width l and the number of

lines k, based on the processing region information supplied

from the processing region setting unit 15081, and the flow

proceeds to step S15102.

15   In step S15102, the model generating unit 15091

acquires the movement amount v, which is equivalent to the

number of lines k in the processing region 15042, from the

continuity setting unit 15082, and the flow proceeds to step

S15103.

20   In step S15103, the model generating unit 15091

generates an equation for the mixed pixel value P_i for each

line, and the flow proceeds to step S15104.   In other words,

the model generating unit 15091 generates k number of model

equations (expressions (141)).

25   In step S15104, the constraint condition setting unit

15101 selects the constraint condition expression

corresponding to the constraint condition information

supplied from the user I/F 15086, from the constraint

condition expressions existing within the constraint

5   condition setting unit itself. Also, the constraint

condition setting unit 15101 acquires the processing region

width l from the processing region information of the input

image which is supplied from the equation generating unit

15092 from the processing region setting unit 15081, and

10   generates an constraint condition Expression (Expression

(145)) corresponding to the constraint condition information

from the user I/F 15086, which comprises a number of

equations corresponding to the processing region width l,

and the flow proceeds to step S15105.

15   In step S15105, the weighting changing unit 15102

supplies the weighting coefficient W expressed by Expression

(153), which is set in advance internally within the

weighting changing unit 15102 itself, to the normal equation

generating unit 15103, and changes the weighting as to the

20   constraint condition expression, and the flow proceeds to

step S15106. That is to say, the weighting changing unit

15102 generates the above-described Expression (154) at the

normal equation generating unit 15103.

     In step S15106, the normal equation generating unit

25   15103 selects one predetermined line as the line of interest

from the processing region 15042, and the flow proceeds to step S15107.

In step S15107, the normal equation generating unit 15103 generates a normal equation expressed by Expression (155) (Expression (156)) from Expression (146), wherein the error e_{mi} is considered of the various expressions of the equation of the mixed pixel value P_i expressed by Expression (141), which is supplied from the model generating unit 15091, and the constraint condition Expression (154) obtained by changing the weighting of Expression (147) wherein the error e_{bj} is considered regarding Expression (145) which is supplied from the constraint condition setting unit 15101, by the weighting changing unit 15102 in step S15105, and the flow proceeds to step S15108.

In step S15108, the normal equation generating unit 15103 computes the matrix $(A'^{T}A')^{-1}A'^{T}$, which is a coefficient of the column vector y of the right side of Expression (158), and the flow proceeds to step S15109.

In step S15109, the normal equation generating unit 15103 substitutes the mixed pixel value P_i which is acquired based on the input image supplied from the sensor 2 (Fig. 1) into the column vector y, and the flow proceeds to step S15110.

In step S15110, the actual world waveform estimating unit 15093 computes a normal equation. That is to say, the

actual world waveform estimating unit 15093 finds a pixel

value Q_h with no movement blurring by computing Expression

(158) which is supplied from the normal equation generating

unit 15103, and the flow proceeds to step S15111.

5   In step S15111, determination is made as to whether or

not processing is performed to find a pixel value Q_h with no

movement blurring as to all lines of the processing region

15042. In the event that it is determined that processing

is not performed to find a pixel value Q_h with no movement

10   blurring as to all lines of the processing region 15042, the

process is returned to step S15106, and the processing in

steps S15106 through S15111 is repeated. That is to say, a

line not yet selected of the processing region 15042 is

selected as the next line of interest, and processing is

15   performed to find a pixel value Q_h with no movement blurring.

On the other hand, in the event that it is determined

that processing is performed to find a pixel value Q_h with

no movement blurring as to all lines of the processing

region 15042, the actual world estimating processing ends

20   and returns.

Thus, by generating a normal equation (Expression

(155)) as to one line which is the line of interest of the

processing region 15042, and repeating the processing to

find a pixel value Q_h with no movement blurring k number of

25   times, which is the number of lines in the processing region

15042, the pixel value Q_h with no movement blurring can be found across the entire region of the processing region 15042.

In the event that the movement amount v and the

5   processing region width l are each the same for each line of the processing region 15042, the matrix A in Expression (155) is the same for every line. Accordingly, the matrix $(A'^T A')^{-1} A'^T$ in Expression (158) also is the same for every line, and the processing to compute the matrix $(A'^T A')^{-1} A'^T$

10   for each line can be omitted.

Next, the actual world estimating processing of the actual world estimating unit 15083 in step S15088 in Fig. 136 in the event that the movement amount v and the processing region width l are each the same for each line of

15   the processing region 15042 will be described with reference to the flowchart of Fig. 139. However, the portions in Fig. 139 which are similar to the flowchart in Fig. 138 will omit the description thereof as appropriate.

In Fig. 139, the processing in step S15138 which

20   corresponds to step S15106 in Fig. 138 is positioned not between step S15135 and S15136, but between steps S15137 and S15139. Further, in step S15141, if it is determined that processing is not performed to find a pixel value Q_h with no movement blurring as to all lines of the processing region

25   15042, the process is returned to step S15138.

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In other words, in the event that the movement amount v
and the processing region width l of each line of the
processing region 15042 are each the same, the normal
equation generated in step S15136 is the same for each line,

5   and therefore, after computing the matrix $(A'^{T}A')^{-1}A'^{T}$ as to
the first line of interest in step S15137, computing the
matrix $(A'^{T}A')^{-1}A'^{T}$ as to the remaining lines of interest
(the processing in step S15137) is not necessary.
Accordingly, the selection of the line of interest (step

10   S15138), the substitution of the mixed pixel value P_i (the
processing in step S15139), and the computation of the
normal equation (the processing in step S15140) only need be
executed in order, as to the lines not selected in the
processing region 15042.

15   Thus, with the embodiment illustrated in Fig. 135, a
normal equation is generated from an equation of the mixed
pixel value P_i wherein a pixel value generating movement
blurring is modeled with a pixel value with no movement
blurring (model equation), and a constraint condition

20   expression using the relation between adjacent pixels of a
pixel value with no movement blurring, and by computing this
normal equation, a pixel value with no movement blurring
(approximation function) is found, and therefore an image
with good image quality can be generated.

25   Also, because the balance (weighting) of the mixed

pixel value Pi equation and the constraint condition

expression can be adjusted, an image can be generated with

no movement blurring, which considers "sharpness" and

"noise" and has the image quality according to the

5   preference of the user.

With the above-described example, the constraint

condition information supplied from the user I/F 15086 to

the constraint condition setting unit 15101 is said to be

information showing which constraint condition the user has

10 selected (instructed), out of the multiple constraint

conditions previously set internally in the constraint

condition setting unit 15101, but it may be set up such that

that user can directly input the constraint condition

expression by operating the user I/F 15086.

15 With the embodiment of the signal processing device 4

in Fig. 135, the weighting coefficient W relating to the

constraint condition expression, which adjusts the weighting

(balance) of the mixed pixel value Pi equation and the

constraint condition expression, has been a predetermined

20 value which is set in advance (0.1 in the above case).

However, setting the weighting coefficient W relating

to the constraint condition expression as a predetermined

value (fixed value) is to apply the constraint conditions as

to the places (relation between pixels) wherein the

25 constraint condition is not established, similar to the

places wherein the constraint condition is established, which causes deterioration of the processing image in some cases.

Therefore, next, an embodiment will be described

5   wherein the signal processing device 4 can determine the weighting relating to the constraint condition expression and so forth corresponding to the activity (features) of the input image.

Fig. 140 is a configuration example of another

10   embodiment with an application example of the signal processing device 4 illustrated in Fig. 111.

An image of, for example, one frame or one field as the data 3 from the sensor 2 is input into the signal processing device 4 in Fig. 140. Here, an object having a

15   predetermined shape is displayed in the input image, such object moving in the horizontal direction (crosswise direction) of the image at a constant speed of v pixels per shutter time (exposure time). In other words, regarding the input image, the object is moving in a horizontal direction

20   at the movement amount of v pixels, and therefore because of the time integration effect of the sensor 2, the light signal of the object and the light signal of the portion other than the object are mixed (time mixture), and thus, the image is blurred at portions such as the borders of the

25   object. With the signal processing device 4 in Fig. 140, a

high-quality output image is generated which has removed movement blurring from the input image what had occurred due to such time mixture.

In Fig. 140, the processing region setting unit 15111, the continuity setting unit 15112, the actual world estimating unit 15113, image generating unit 15114, image display unit 15115, and user I/F 15116, each correspond to the processing region setting unit 10001, the continuity setting unit 10002, the actual world estimating unit 10003, image generating unit 10004, image display unit 10005, and user I/F 10006 shown in Fig. 111, and basically perform the same processing as the processing region setting unit 10001, the continuity setting unit 10002, the actual world estimating unit 10003, image generating unit 10004, image display unit 10005, and user I/F 10006. Further, in Fig. 140, the actual world estimating unit 15113 comprises a model generating unit 15121, an equation generating unit 15122, and actual world waveform estimating unit 15123. The model generating unit 15121, equation generating unit 15122, and actual world waveform estimating unit 15123 correspond to each of the model generating unit 10011, equation generating unit 10012, and actual world waveform estimating unit 10013 in Fig. 111, and basically perform the same functions as each of the model generating unit 10011, equation generating unit 10012, and actual world waveform

estimating unit 10013.

Note however, that in Fig. 140, the assisting
information which the user I/F 15116 outputs by the user
operating the user I/F 15116, is supplied to the equation
5 generating unit 15122.

In other words, in Fig. 140, by operating the user I/F
15116, with the equation generating unit 15122, the user can
set the constraint conditions which constrain the relation
between each of the pixels of an image with no movement
10 blurring, which is an image of the actual world 1
corresponding to the input image, and when the user performs
an operation to set the constraint conditions, the user I/F
15116 supplies the constraint condition information
expressing the constraint conditions set by the operation to
15 the equation generating unit 15122.

Specifically, for example, a user who views an image
displayed on the image display unit 15115 reflecting a
blurring image guesses the original image, that is to say,
an image without movement blurring which is an image of the
20 actual world 1 corresponding to the input image. Also, for
example, the user guesses predetermined regions where
blurring is occurring as the edge portions, and guesses the
relation of the pixel values between each of the pixels (the
constraint conditions), such as the difference being large
25 between the pixel values (level) between the adjacent pixels

at the edge portions. Further, the user can set the

conditions suitable for the guessed relation of the pixels

value between each of the pixels into the equation

generating unit 15122, by operating the user I/F 15116.

5   Also, in Fig. 140, the processing region information,

which is supplied from the processing region setting unit

15111 to the actual world estimating unit 15113, is supplied

to the model generating unit 15121 and the equation

generating unit 15122 of the actual world estimating unit

10   15113. The model generating unit 15121 and the equation

generating unit 15122 recognize the processing region in the

input image from the processing region information supplied

from the processing region setting unit 15111.

The continuity setting unit 15112 sets a movement

15   amount (movement vector) v in the input image as the

continuity information that an object is moving in the

horizontal direction of the image at the constant speed of v

pixels per shutter time, and supplies this movement amount v

as the continuity information to the model generating unit

20   15121 of the actual world estimating unit 15113.

The model generating unit 15121 generates an equation

(hereafter referred to as model equation as appropriate) as

a model (hereafter referred to as relation model as

appropriate), modeling the relation between the signal of

25   the actual world 1 and the pixel values of each of the

pixels of the movement blurring image as the input image
which considers the movement amount v as the continuity
information supplied from the continuity setting unit 15112,
regarding the processing region recognized by the processing

5   region information which is supplied from the processing
region setting unit 15111, and supplies the generated model
equation to the equation generating unit 15122.

The equation generating unit 15122 generates a
constraint condition Expression (hereafter referred to as

10   constraint condition expression as appropriate), based on
the constraint condition information supplied from the user
I/F 15116. Also, the equation generating unit 15122 sets
the weighting to be determined by the activity of the input
image into the constraint condition expression and the model

15   equation supplied from the model generating unit 15121, and
substitutes the pixel values of each of the pixels of the
input image comprising the processing region into the
equation formed from the weighted constraint condition
expression and the model equation, and thus, generates an

20   equation to find the approximation function as a model
(hereafter referred to as approximation model) wherein the
signal of the actual world 1 is modeled, and supplies this
to the actual world waveform estimating unit 15123.

The actual world waveform estimating unit 15123

25   estimates the waveform of the actual world 1 signals, by

computing the equation supplied from the equation generating

unit 15122. In other words, the actual world waveform

estimating unit 15123 finds the approximation function as an

approximation model, and supplies the approximation function

5   to the image generating unit 15114 as the estimation result

of the signal waveform of the actual world 1. Note that

approximation function approximating the actual world 1

signals include functions with constant function values,

regardless of argument value.

10   The image generating unit 15114 recognizes the

processing region in the input image from the processing

region information supplied from the processing region

setting unit 15111. Also, the image generating unit 15114

generates a signal more closely approximating the signal of

15   the actual world 1, from the approximation function supplied

from the actual world waveform estimating unit 15123, that

is to say, generates an image with no movement blurring, and

replaces the image of the processing region of the input

image with an image wherein the image has no movement

20   blurring, generates this as an output image, and supplies

this to the image display unit 15115.

Next, the processing of the signal processing device 4

in Fig. 140 will be described with reference to the

flowchart in Fig. 141.

25   First, in step S15161, the signal processing device 4

performs pre-processing, and the flow proceeds to step

S15162. That is to say, the signal processing device 4

supplies one frame or one field, for example, of the input

image, supplied from the sensor 2 (Fig. 1) as data 3, to the

5   processing region setting unit 15111, continuity setting

unit 15112, actual world estimating unit 15113, image

generating unit 15114, and image display unit 15115.

Further, the signal processing unit 4 causes the image

display unit 15115 to display the input image.

10   In step S15162, the user I/F 15116 determines whether

or not there has been some sort of user input, by the user

operating the user I/F 15116. In step S15162, in the event

that determination is made that there is no user input, i.e.,

in the event that the user has made no operations, the flow

15   skips steps S15163 through S15165, and proceeds to step

S15166.

On the other hand, in step S15162, in the event that

determination is made that there has been user input, i.e.,

in the event that the user has viewed the input image

20   displayed on the image display unit 15115 and operated the

user I/F 15116, thereby making user input indicating some

sort of instruction or information, the flow proceeds to

step S15163, where the user I/F 15116 determines whether or

not the user input is user instructions instructing ending

25   of the processing of the signal processing device 4.

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In the event that determination is made that in step S15163 that the user input is ending instructions, the signal processing device 4 ends the processing.

On the other hand, in the event that determination is
5   made in step S15163 that the user input is not ending instructions, the flow proceeds to step S15164, where the user I/F 15166 determines whether or not the user input is constraint condition instruction information. In the event that determination is made in step S15164 that the user
10   input is not constraint condition instruction information, step S15165 is skipped, and the flow proceeds to step S15166.

Also, in step S15164, in the event that the user input is determined to be constraint condition information, the flow proceeds to step S15165, and the user I/F 15116
15   supplies the constraint condition information to the equation generating unit 15122, and the flow proceeds to step S15166.

In step S15166, the processing region setting unit 15111 sets the processing region based on the input image,
20   and supplies the processing region information identifying the processing region to the continuity setting unit 15112, the model generating unit 15121 and equation generating unit 15122 of the actual world estimating unit 15113, and image generating unit 15114, and the flow proceeds to step S15167.
25   Now, an arrangement maybe made wherein the setting of the

processing region in step S15166 is performed by the user

inputting processing region instruction information by

operating the user I/F 15116, so as to be carried out based

on the processing region instruction information, or, this

5   may be carried out without processing region instruction

information from the user.

In step S15167, the continuity setting unit 15112

recognizes the processing region in the input image, from

the processing region information supplied from the

10   processing region setting unit 15111. Further, the

continuity setting unit 15112 sets continuity of a part of

the continuity of the actual world 1 signals that has been

lost in the image data of the processing region, and

supplies continuity information indicating the continuity

15   thereof to the model generating unit 15121 of the actual

world estimating unit 15113, and the flow proceeds to step

S15168. Here, the continuity setting unit 15112 sets the

movement amount v, expressing that the movement is in the

horizontal direction at a constant speed of v pixels per

20   shutter time (exposure time), as the continuity information,

and supplies this to the model generating unit 15121 of the

actual world estimating unit 15113. Here, the continuity

setting unit 15112 sets the movement amount showing only the

movement size as continuity information, under the premise

25   that the object is moving in a horizontal direction, but a

movement vector showing the size and direction of the
movement of the object can be set as continuity information
as well. Now, an arrangement may be made wherein the
setting of the continuity in step S15167 is performed by the
5   user inputting continuity instruction information by
operating the user I/F 15116, so as to be carried out based
on the continuity instruction information, or, this may be
carried out without continuity instruction information

The actual world estimating unit 15113 performs actual
10   world estimating processing in step S15168. In other words,
with the actual world estimating unit 15113, the model
generating unit 15121 generates an equation (model equation)
as the model (relation model) wherein the relation of the
pixel values of each of the pixels of the input image which
15   has movement blurring and the signal of the actual world 1
is modeled, based on the movement amount v supplied from the
continuity setting unit 15112 in step S15167 and the
processing region information supplied from the processing
region setting unit 15111 in step S15166, and the generated
20   model equation is supplied to the equation generating unit
15122.

The equation generating unit 15122 generates a
constraint condition expression based on the constraint
condition information supplied from the user I/F 15116 in
25   step S15165, and sets the weighting determined from the

activity of the input image into the generated constraint
condition expression and the model equation supplied from
the model generating unit 15121 to the equation generating
unit 15122. Then, the equation generating unit 15122

5 substitutes the pixel values of each of the pixels of the
input image comprising the processing region into the
equation formed from the weighted constraint condition
expression and the model equation, and thus generates the
equation for finding the approximation function as a model

10 (approximate model) wherein the signal of the actual world 1
is modeled, and supplies this to the actual world waveform
estimating unit 15123. In the event that the user has not
specified (set) constraint condition information, that is to
say, in the event that NO is determined to be the case in

15 step S15162 or S15164, the equation generating unit 15122
performs predetermined processing such as a method for
solving a simultaneous equation formed of a model equation
and an equation hypothesizing that the edge portions of the
processing region is "flat", as described in the embodiment

20 in Fig. 113, for example.

The actual world waveform estimating unit 15123
estimates the waveform of the actual world 1 signals, by
computing the equation supplied from the equation generating
unit 15122, that is to say, the actual world waveform

25 estimating unit 15123 obtains an approximation function

modeling the actual world 1 signals, and supplies the
approximation function to the image generating unit 15114,
as estimation results of the waveform of the actual world 1
signals.

5   The details of the actual world estimating processing
in step S15168 will be described later with reference to Fig.
143.

       After the processing in step S15168, the flow proceeds
to step S15169, and the image generating unit 15114
10   generates a signal more closely approximating the signal of
the actual world 1, from the approximation function supplied
from the actual world waveform estimating unit 15123, that
is to say, generates an image with no movement blurring, and
based on the processing region information supplied from the
15   processing region setting unit 15111, converts the portion
of the processing region of the input image into an image
which has no movement blurring generated, generates this as
an output image, and supplies this to the image display unit
15115, and the flow proceeds to step S15170.

20   In step S15170, the image display unit 15115 displays
the output image supplied from the image generating unit
15114 instead of the input image displayed in step S15161,
or along with the input image, and the flow proceeds to step
S15171.

25   In step S15171, as with the case of step S15162, the

user I/F 15116 determines whether or not there has been some

sort of user input by the user operating the user I/F 15116,

and in the event that determination is made that there has

been no user input, i.e., in the event that the user has

5   made no operations, the flow returns to step S15171, and

awaits some sort of user input.

Also, in the event that determination is made in step

S15171 that there has been user input, i.e., in the event

that the user has viewed the input image or output image

10   displayed on the image display unit 15115 and operated the

user I/F 15116, thereby making user input representing some

sort of instructions or information, the flow proceeds to

step S15172, where the user I/F 15116 determines whether or

not the user input is ending instructions instructing ending

15   of the processing of the signal processing device 4.

In the event that determination is made in step S15172

that the user input is ending instructions, the signal

processing device 4 ends the processing.

On the other hand, in the event that determination is

20   made in step S15172 that the user input is not ending

instructions, the flow proceeds to step S15173, where the

user I/F 15116 determines whether or not the user input is

constraint condition information. In the event that

determination is made in step S15173 that the user input is

25   not constraint condition information, the flow returns to

step S15171, and hereafter the same processing is repeated.

Also, in step S15173, in the event that determination
is made that the user input is constraint condition
information, the flow returns to step S15165, and as

5 described above, the user I/F 15116 supplies the constraint
condition information to the equation generating unit 15122.
The flow then proceeds from step S15165 to step S15166, and
hereafter the same processing is repeated. In the event
that the signal processing device 4 repeats the processing

10 of step S15165 through step S15173, the processing of the
above-described step S15166 and S15167 is the same as that
set by the first processing S15166 and S15167, and the same
process as the first process may be repeated, or may be
skipped.

15 Thus, with the signal processing device 4 in Fig. 140,
by finding an approximation function as a model wherein the
signal of the actual world 1 is modeled, an output image of
high image quality with no movement blurring can be
generated.

20 Also, by operating the user I/F 15116, the user can set
constraint conditions which constrain the relation between
each of the pixels in the original image having no movement
blurring, and in the event that a new constraint condition
is input, an image without movement blurring can be obtained

25 again, and therefore an output image of high image quality

according to the preference of the user can be easily

acquired.

With the signal processing device 4 in Fig. 140, an

output image without movement blurring is generated by

5   finding an approximation function which approximates the

light signal of the actual world 1, but this output image

can be regarded as having the movement blurring removed from

the input image. Accordingly, it can be said that

processing is performed for movement blurring removal with

10   the signal processing device 4 in Fig. 140.

Next, the configuration of the inside of the actual

world estimating unit 15113 in Fig. 140 will be described

with reference to Fig. 142. With the embodiment in Fig. 140

also, the mechanism for movement blurring generation of the

15   object projected on the input image is modeled as the

relation of the above-described Expression (141),

illustrated in Fig. 125 and Fig. 126 which is one example

thereof.

In other words, let us say that the mechanism for

20   moment blurring generation is modeled assuming that the

pixel values of each of the pixels of the movement blurring

image as the input image are values wherein the pixel values

(or the electric charge corresponding thereto) of each of

the pixels of an image with no movement blurring which are

25   accumulated (integrated) while moving at the movement amount

v.

The actual world estimating unit 15113 comprises a model generating unit 15121, an equation generating unit 15122, and an actual world waveform estimating unit 15123.

5   Further, the equation generating unit 15122 comprises a constraint condition setting unit 15131, an activity detecting unit 15132, a weighting changing unit 15133, and a normal equation generating unit 15134.

The movement amount v as the continuity information is

10   supplied to the model generating unit 15121 by the continuity setting unit 15112. The movement amount v in this example expresses the continuity of the object moving in the horizontal direction at a constant speed of v pixels per shutter time, within the processing region of the input

15   image which is set in the processing region setting unit 15111, and for example, let us say that v = 4, as with the above-described example. Also, the movement amount v may be a value which differs for each line, and in the event that the movement amount v differs for each line, k number, equal

20   to the number of lines, of the movement amount v is supplied as continuity information from the continuity setting unit 15112 to the model generating unit 15121.

Also, processing region information which specifies the processing region within the input image is also supplied to

25   the model generating unit 15121 from the processing region

setting unit 15111. In the case of employing a rectangular-shaped region as the processing region, the processing region information can be expressed, for example, by coordinate values at opposite angles of a rectangular-shaped

5   processing region as to an absolute coordinate system wherein a predetermined position (pixel) of the input image is the origin, or the center coordinate of the processing region and the width (horizontal direction) and the height (vertical direction) of the processing region.

10   The model generating unit 15121 acquires, for example, a processing region width of l, and k line numbers, as illustrated in Fig. 119, from the processing region information supplied from the processing region setting unit 15111. In this example, let us say that the processing

15   region 15042 is rectangular-shaped, and for example, has l = 10 and k = 4. In this case, the processing region width of each line (the number of pixels) are the same, but with the processing region 15042, each line can have a different processing region width. In the case that the processing

20   region width l differs for each line, the model generating unit 15121 acquires a processing region width l of the same number (k) as the number of lines.

Also, the model generating unit 15121 generates an equation (model equation) of a mixed pixel value P_i (i = 3

25   through 9) which is shown in the above-described Expression

(141), based on the movement amount v supplied from the continuity setting unit 15112 and the processing region width l and k number of lines acquired from the processing region information, and supplies this to the normal equation

5 generating unit 15134.

The constraint condition information specified by the user operating the user I/F 15116 is supplied to the constraint condition setting unit 15131 from the user I/F 15116. For example, the user performs an operation with the

10 user I/F 15116 to select (specify) the desired constraint condition from the constraint conditions which constrain the relation of the pixel values Q_h of each of the pixels of an image with no movement blurring, such as the above-described Expression (143) or Expression (144), which have been set in

15 advance inside the constraint condition setting unit 15131, and the user I/F 15116 supplies the information describing the selected constraint conditions as the constraint condition information to the constraint condition setting unit 15131.

20 The constraint condition setting unit 15131 selects a constraint condition expression corresponding to the constraint condition information supplied from the user I/F 15116 from the constraint condition expressions within the constraint condition setting unit 15131 itself. Further,

25 the constraint condition setting unit 15131 acquires the

processing region width l based on the processing region information of the input image supplied to the equation generating unit 15122 from the processing region setting unit 15111, and generates only the number, which corresponds

5   to the processing region width l, of the constraint condition expressions. For example, in the event that Expression (143) is employed which has the condition "adjacent pixel difference = 0" as the constraint condition information, the constraint condition setting unit 15131

10 generates the constraint condition expression expressed by the above-described Expression (145), by acquiring the processing region width l based on the processing region information supplied from the processing region setting unit 15111, and supplies this to the normal equation generating

15 unit 15134. In the example of the processing region 15042 illustrated in Fig. 119, the processing region 15042 is rectangular-shaped, and the processing region width l is the same of each line, but in the case that the processing region width l differs for each line, the number of

20 constraint condition expressions also differ for each line.

    With the activity detecting unit 15132, the activity (features) of each of the pixels (pixel of interest) within the processing region of the input image, which is to become information for the purpose of the weighting changing unit

25 15133 to determine the weighting W_{mi} as to the equation of

each of the mixed pixels Pi (model equation) and the weighting W_{bj} as to each of the constraint condition expressions, is detected.

In other words, the activity detecting unit 15132
5 detects the value of the adjacent pixel difference (P_j - P_{j+1}) between the value of the pixel of interest P_j and the pixel P_{j+1} adjacent to the right thereof, or the like, for example, with each of the pixels within the processing region of the input image as a pixel of interest P_j, for
10 example, as activity of the pixel of interest P_j, and supplies this to the weighting changing unit 15133.

The weighting changing unit 15133 has a weighting W_{mi} (hereafter will be simply called weighting W_{mi}) as to the equation for each of the mixed pixel values P_i (the model
15 equation) and a weighting W_{bj} (hereafter will be simply called weighting W_{bj}) as to each of the constraint condition expressions.

By supplying the weighting W_{mi} and the weighting W_{bj} to the normal equation generating unit 15134, the weighting
20 changing unit 15133 changes (sets) the weighting of each of the equations of the mixed pixel value P_i equation supplied from the model generating unit 15121 (the model equation), and the equation formed from the constraint condition expressions supplied from the constraint condition setting
25 unit 15131, which are generated in the normal equation

generating unit 15134.

The deterioration of the image comprised by the pixel value Q_h acquired with the actual world estimating unit 15113 can be conceived to occur often in positions where the

5   constraint condition is inappropriate, and thus, adjusting the weighting W_{bj} appropriately is more effective than the weighting W_{mi}.   Thus, with this embodiment, the weighting W_{mi} is a predetermined value (fixed value), and the weighting W_{bj} is changed based on the activity supplied from the activity

10 detecting unit 15132.   Now, the weighting W_{mi} may also be made to be changed by the activity found with similar methods to be described below, or by other methods.

In the event that the "adjacent pixel difference = 0" expressed by the above-described Expression (143), for

15 example, is employed as a constraint condition expression, the positions (pixels) wherein the constraint condition expression expressed by Expression (143) is not established are pixels corresponding to the edge portions of the object in the image with no movement blurring.   Here, the

20 constraint condition expression expressed by Expression (143) considers the difference between adjacent pixels in the direction of the spatial direction X, and therefore, the edge portion of the object wherein the constraint condition expression is not established is the edge in the direction

25 that the object edge direction (border line) is not in the

horizontal direction (a parallel direction to the spatial direction X).

The edge portion of the image with no movement blurring occurring is also the edge in an image with movement

5   blurring. In other words, a pixel which was an edge portion in an image with no movement blurring occurring still has the characteristics of the edge in the vicinity of this pixel even in an image with movement blurring occurring. Accordingly, the weighting W_{bj} can be determined according to

10   the value of the adjacent pixel difference $(P_j - P_{j+1})$ of the image (input image) wherein movement blurring is occurring.

In other words, positions with a large value of the adjacent pixel difference $(P_j - P_{j+1})$ of the input image has a greater probability of being an edge in an image with no

15   movement blurring occurring. Thus, the weighting W_{bj} of the constraint condition expression in the above-described Expression (143) wherein the adjacent pixel difference is small is made to be smaller (the constraint condition is relaxed). There are two methods as will be described below,

20   for example, as methods for causing the weighting W_{bj} to be smaller corresponding to the adjacent pixel difference $(P_j - P_{j+1})$ which shows activity.

The first method is a method employing the inverse ratio of the value of the adjacent pixel difference $(P_j - $

25   $P_{j+1})$ of the input image as the weighting W_{bj}. This can be

expressed as the following Expression.

$$W_{bj} = \frac{1}{P_j - P_{j+1}} \qquad j = 0, \cdots, 8$$

$$\cdots (159)$$

The second method is a method setting the weighting W_{bj}

5   of the constraint condition as either 0 or 1, according to

the value of the adjacent pixel difference ($P_j - P_{j+1}$) of the

input image, and equivalently determining whether or not to

include the constraint condition expression. This can be

expressed as the following Expression.

$$W_{bj} = \begin{cases} 0 & (P_j - P_{j+1} > Th) \\ 1 & (P_j - P_{j+1} < Th) \end{cases} \qquad j = 0, \cdots, 8$$

10

$$\cdots (160)$$

Here, in Expression (160), the threshold value Th is a

value which is the basis for determining whether or not to

include the constraint condition expression, and can be set

15   in advance in the weighting changing unit 15133. The

constraint condition expression wherein the weighting W_{bj} is

set as 0 is essentially removed from the condition

constraint expression.

The equation of the mixed pixel value P_i having the same

20   number k as the number of lines (Expression (141)) is

supplied to the normal equation generating unit 15134 from

the model generating unit 15121. Also, the constraint

condition Expression (Expression (145)) corresponding to the

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constraint condition selected by the user operating the user I/F 15116 is supplied to the normal equation generating unit 15134 from the constraint condition setting unit 15132.

   With the normal equation generating unit 15134, the

5   weighting W_{bj} is set for Expression (147) wherein the error e_{bj} is considered to the constraint condition Expression (145) supplied from the constraint condition setting unit 15132, by the weighting changing unit 15133 (the weighting W_{bj} as to the model equation and the constraint condition

10   which was has been 1:1 is changed).

   In other words, Expression (147) is changed to the following Expression (161) which has multiplied both sides thereof by W_{bj}.

$$W_{b0}(Q_0-Q_1) = W_{b0}e_{b0}$$
$$W_{b1}(Q_1-Q_2) = W_{b1}e_{b1}$$
$$W_{b2}(Q_2-Q_3) = W_{b2}e_{b2}$$
$$W_{b3}(Q_3-Q_4) = W_{b3}e_{b3}$$
$$W_{b4}(Q_4-Q_5) = W_{b4}e_{b4}$$
$$W_{b5}(Q_5-Q_6) = W_{b5}e_{b5}$$
$$W_{b6}(Q_6-Q_7) = W_{b6}e_{b6}$$
$$W_{b7}(Q_7-Q_8) = W_{b7}e_{b7}$$
$$W_{b8}(Q_8-Q_9) = W_{b8}e_{b8}$$

15   ... (161)

   Also, with the normal equation generating unit 15134, the weighting W_{mi} is set for Expression (146) wherein the

error e_{mi} is considered to the mixed pixel value P_i equation (model equation) (141) supplied from the model generating unit 15121, by the weighting changing unit 15133.

In other words, Expression (146) is changed to the
5 following Expression (162) which has multiplied both sides thereof by the weighting W_{mi}.

$$W_{m3} \times (Q_0+Q_1+Q_2+Q_3)/v = W_{m3} \times (P_3+e_{m3})$$
$$W_{m4} \times (Q_1+Q_2+Q_3+Q_4)/v = W_{m4} \times (P_4+e_{m4})$$
$$W_{m5} \times (Q_2+Q_3+Q_4+Q_5)/v = W_{m5} \times (P_5+e_{m5})$$
$$W_{m6} \times (Q_3+Q_4+Q_5+Q_6)/v = W_{m6} \times (P_6+e_{m6})$$
$$W_{m7} \times (Q_4+Q_5+Q_6+Q_7)/v = W_{m7} \times (P_7+e_{m7})$$
$$W_{m8} \times (Q_5+Q_6+Q_7+Q_8)/v = W_{m8} \times (P_8+e_{m8})$$
$$W_{m9} \times (Q_6+Q_7+Q_8+Q_9)/v = W_{m9} \times (P_9+e_{m9})$$

... (162)

As described above, the weighting W_{mi} in Expression
10 (162) is a fixed value, here.

As illustrated in Fig. 128, the normal equation generating unit 15134 selects one predetermined line from the processing region 15042 as the line of interest. Then the normal equation generating unit 15134 generates a normal
15 equation expressed with the following Expression (163) from Expression (161) and Expression (162) corresponding to the selected line of interest.

$$\begin{bmatrix} W_{m3} \\ W_{m4} \\ W_{m5} \\ W_{m6} \\ W_{m7} \\ W_{m8} \\ W_{m9} \\ W_{b0} \\ W_{b1} \\ W_{b2} \\ W_{b3} \\ W_{b4} \\ W_{b5} \\ W_{b6} \\ W_{b7} \\ W_{b8} \end{bmatrix}^T \begin{bmatrix} 1/v & 1/v & 1/v & 1/v & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1/v & 1/v & 1/v & 1/v & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1/v & 1/v & 1/v & 1/v & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1/v & 1/v & 1/v & 1/v & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1/v & 1/v & 1/v & 1/v & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1/v & 1/v & 1/v & 1/v & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1/v & 1/v & 1/v & 1/v \\ 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 \end{bmatrix} \begin{bmatrix} Q_0 \\ Q_1 \\ Q_2 \\ Q_3 \\ Q_4 \\ Q_5 \\ Q_6 \\ Q_7 \\ Q_8 \\ Q_9 \end{bmatrix} = \begin{bmatrix} W_{m3} \\ W_{m4} \\ W_{m5} \\ W_{m6} \\ W_{m7} \\ W_{m8} \\ W_{m9} \\ W_{b0} \\ W_{b1} \\ W_{b2} \\ W_{b3} \\ W_{b4} \\ W_{b5} \\ W_{b6} \\ W_{b7} \\ W_{b8} \end{bmatrix}^T \left(\begin{bmatrix} P_3 \\ P_4 \\ P_5 \\ P_6 \\ P_7 \\ P_8 \\ P_9 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} e_{m3} \\ e_{m4} \\ e_{m5} \\ e_{m6} \\ e_{m7} \\ e_{m8} \\ e_{m9} \\ e_{b0} \\ e_{b1} \\ e_{b2} \\ e_{b3} \\ e_{b4} \\ e_{b5} \\ e_{b6} \\ e_{b7} \\ e_{b8} \end{bmatrix} \right)$$

$$\ldots (163)$$

Here, Expression (163) is replaced with Expression (164), using the matrix A" and the column vectors x, y, e".

$$A''x = y + e''$$

$$\ldots (164)$$

In this case, the total sum E of the squared errors of the error e_{bj} of Expression (161) and the error e_{mi} of Expression (162) can be expressed with the following expression.

$$E'' = \sum (W_{mi} e_{mi})^2 + \sum (W_{bj} e_{bj})^2$$

... (165)

In order to find the Q_h which causes the total sum E" of
the squared error to be very small, the column vector x (the
column vector x with the pixel value Q_h as a component

5   thereof) can be expressed with Expression (166) from the
same expression as the above Expression (150) and Expression
(151).

$$x = (A''^T A'')^{-1} A''^T y$$

... (166)

10   Now, with Expression (166), the superscript T means
transposing, and the superscript -1 means an inverse matrix.

Accordingly, the normal equation generating unit 15134
computes the matrix $(A''^T A'')^{-1} A''^T$, which is a coefficient of
the column vector y of the right side of Expression (166),

15   and substitutes the mixed pixel value P_i which is acquired
based on the input image supplied from the sensor 2 (Fig. 1)
into the column vector y. The matrix $(A''^T A'')^{-1} A''^T$ is
computed, and Expression (166) into which the mixed pixel
value P_i is substituted is supplied from the normal equation

20   generating unit 15134 to the actual world waveform
estimating unit 15123.

When the processing such as described above is finished
wherein one predetermined line of the processing region
15042 is selected as the line of interest, the normal

equation generating unit 15134 selects a line not yet
selected as the next line of interest, and similar
processing is performed as to the selected next line of
interest.

5   The actual world waveform estimating unit 15123, by
computing Expression (166) which is supplied from the normal
equation generating unit 15134, finds the column vector x,
that is to say, the pixel value Q_h with no movement blurring,
and supplies this to the image generating unit 15114 (Fig.

10   140).

The image generating unit 15114 replaces a portion of
the processing region 15042 of the input image with the
image of the pixel value Q_h with no movement blurring, which
is supplied from the actual world waveform estimating unit

15   15123, based on the processing region information supplied
from the processing region setting unit 15111, and generates
this as an output image, and supplies this to the image
display unit 15115.

Next, the actual world estimating processing of the

20   actual world estimating unit 15113 in step S15168 in Fig.
141 will be described with reference to the flowchart in Fig.
143.

First, in step S15191, the model generating unit 15121
acquires the processing region width 1 and the number of

25   lines k, based on the processing region information supplied

from the processing region setting unit 15111, and the flow proceeds to step S15192.

In step S15192, the model generating unit 15121 acquires a k number of movement amount v, which is equivalent to the number of lines in the processing region 15042, from the continuity setting unit 15112, and the flow proceeds to step S15193.

In step S15193, the model generating unit 15121 generates an equation for the mixed pixel value P_i for each line, and the flow proceeds to step S15194. In other words, the model generating unit 15121 generates k number of model equations (expressions (141)).

In step S15194, the constraint condition setting unit 15131 selects the constraint condition expression corresponding to the constraint condition information supplied from the user I/F 15116, from the constraint condition expressions existing within the constraint condition setting unit itself. Also, the constraint condition setting unit 15131 acquires the processing region width l from the processing region information of the input image which is supplied from the equation generating unit 15122 from the processing region setting unit 15111, and generates an constraint condition Expression (Expression (145)) corresponding to the constraint condition information from the users interface 15116, which comprises a number of

equations corresponding to the processing region width l, and the flow proceeds to step S15195.

In step S15195, the activity detecting unit 15132 detects the activity (features) of each of the pixels within

5   the processing region of the input image which is information for the weighting changing unit 15133 to determine the weighting W_{bj}, and supplies this to the weighting changing unit 15133, and the flow proceeds to step S15196.

10   In step S15196, the weighting changing unit 15133 calculates the weighting W_{bj} to be found with, for example, the above described first or second method, using the activity of each of the pixels within the processing region of the input image, which is supplied from the activity

15   detecting unit 15132. Also, the weighting changing unit 15133 sets the calculated weighting W_{bj} and the weighting W_{mi} provided in advance as a fixed value as the weighting respectively for each of the equations of the mixed pixel value P_i equation of the normal equation generating unit

20   15134 (model equation) and the expression for constraint conditions (constraint condition expression), and the flow proceeds to step S15197.

In step S15197, the normal equation generating unit 15134 selects one predetermined line from the processing

25   region 15042 as a line of interest, and the flow proceeds to

step S15198.

In step S15198, the normal equation generating unit
15134 generates a normal equation expressed by Expression
(163) (Expression (164)), from Expression (162) wherein the
5   weighting W_{mi} is changed by the weighting changing unit 15133
in step S15196, as to Expression (146) which considers the
error e_{mi} of each of the expressions in the equation of the
mixed pixel value Pi expressed with Expression (141), which
is supplied from the model generating unit 15121, and the
10   constraint condition Expression (161) wherein the weighting
W_{bj} is changed by the weighting changing unit 15133 in step
S15196, as to Expression (147) which considers the error e_{bj}
of each of the expressions in the constraint condition
Expression (145), which is supplied from the constraint
15   condition setting unit 15131, and the flow proceeds to step
S15199.

In step S15199, the normal equation generating unit
15134 computes the matrix $(A''^T A'')^{-1} A''^T$, which is a
coefficient of the column vector y of the right side of
20   Expression (166), and the flow proceeds to step S15200.

In step S15200, the normal equation generating unit
15134 substitutes the mixed pixel value P_i which is acquired
based on the input image supplied from the sensor 2 (Fig. 1)
into the column vector y, and the flow proceeds to step
25   S15201.

In step S15201, the actual world waveform estimating unit 15123 computes a normal equation. That is to say, the actual world waveform estimating unit 15123 finds a pixel value Q_h with no movement blurring by computing Expression (166) which is supplied from the normal equation generating unit 15134, and the flow proceeds to step S15202.

In step S15202, determination is made as to whether or not processing is performed to find a pixel value Q_h with no movement blurring as to all lines of the processing region 15042. In the event that it is determined that processing is not performed to find a pixel value Q_h with no movement blurring as to all lines of the processing region 15042, the process is returned to step S15197, and the processing in steps S15197 through S15202 is repeated. That is to say, a line not yet selected of the processing region 15042 is selected as the next line of interest, and processing is performed to find a pixel value Q_h with no movement blurring.

On the other hand, in the event that it is determined that processing is performed to find a pixel value Q_h with no movement blurring as to all lines of the processing region 15042, the actual world estimating processing ends and returns.

Thus, by generating a normal equation (Expression (163)) as to one line which is the line of interest of the processing region 15042, and repeating the processing to

find a pixel value Q_h with no movement blurring k number of times, which is the number of lines in the processing region 15042, the pixel value Q_h with no movement blurring can be found across the entire region of the processing region

5   15042.

Thus, with the embodiment illustrated in Fig. 140, a normal equation is generated from an equation of the mixed pixel value P_i wherein a pixel value generating movement blurring is modeled with a pixel value with no movement

10   blurring, and a constraint condition expression using the relation between adjacent pixels of a pixel value with no movement blurring, and by computing this normal equation, a pixel value with no movement blurring is found, and therefore an image with good image quality can be generated.

15   Also, the weighting of each of the constraint conditions expressions is changed based on the activity of the input image, and therefore an image with good image quality can be generated according to the features of the input image.

20   Figs. 144 through 146 are diagrams describing the processing results of the signal processing device 4 in Fig. 140.

Fig. 144 illustrates an input image to be input in the signal processing device 4 in Fig. 140. With the input

25   image in Fig. 144, the characters "TAL" are moving in the

direction from left to right at the same speed, and movement

blurring is occurring in the horizontal direction.

Fig. 145 illustrates an output image wherein the input

image in Fig. 144 has been processed by the signal

5   processing device 4 in Fig. 135. That is to say, this is an

output image as to the input shown in Fig. 144, wherein the

weighting W_{bj} regarding the constraint conditions is applied

to all constraint condition expressions as the same weight.

As is clear by comparing Fig. 144 and Fig. 145, in the image

10   in Fig. 145, the movement blurring occurring in the input

image in Fig. 144 is reduced, and the characters "TAL" are

relatively clearly displayed.

On the other hand, Fig. 146 illustrates the output

image wherein the input image in Fig. 144 has been processed

15   by the signal processing device 4 in Fig. 140 which is the

above-described embodiment, using the above-described second

method. That is, this is an output image as to the input

shown in Fig. 144, wherein the weighting W_{bj} regarding the

constraint condition expressions is set to 0 or to 1

20   depending on the activity. In the image in Fig. 146 also,

the movement blurring occurring in the input image in Fig.

144 is reduced, and the characters "TAL" are clearly

displayed.

Now, with the embodiment in Fig. 144 through Fig. 146,

25   the processed image in Fig. 146 is an image wherein the edge

portion is clearer than the processed image in Fig. 145.

Also, in the above-described example, the constraint
condition information supplied from the user I/F 15116 to
the constraint condition setting unit 15131 is said to be

5   information showing which constraint condition the user has
selected (specified) from the multiple constraint conditions
set in advance inside the constraint condition setting unit
15131, but the user may directly input the constraint
condition expression by operating the user I/F 15116.

10   Also, in the case that the above-described second
method is used with the weighting changing unit 15133, the
threshold value Th which is a value that is a basis for
determining whether or not to input a constraint condition
expression is said to be set in advance internally, but the

15   user can also adjust the threshold value Th as appropriate
by operating the user I/F 15116 while viewing the processing
image displayed on the image display unit 15115. Fig. 147
illustrates a configuration example of another embodiment of
an application example of the signal processing device 4 in

20   Fig. 111.

An image of, for example, one frame or one field as the
data 3 from the sensor 2 is input into the signal processing
device 4 in Fig. 147. Here, let us say that an object
having a predetermined shape is displayed in the input image,

25   such object moving in the horizontal direction (crosswise

direction) of the image at a constant speed of v pixels per
shutter time (exposure time). In other words, regarding the
input image, the object is moving in the horizontal
direction at the movement amount of v pixels, and therefore

5   because of the time integration effect of the sensor 2, the
light signal of the object and the light signal of the
portion other than the object are mixed (time mixture), and
thus, the image is blurred at portions such as the borders
of the object. Thus, with the signal processing device 4 in

10 Fig. 147, an output image of high image quality with no
movement blurring can be generated by such time mixture.

In Fig. 147, the processing region setting unit 15151,
the continuity setting unit 15152, the actual world
estimating unit 15153, image generating unit 15154, image

15 display unit 15155, and user I/F 15156, each correspond to
the processing region setting unit 10001, the continuity
setting unit 10002, the actual world estimating unit 10003,
image generating unit 10004, image display unit 10005, and
user I/F 10006 shown in Fig. 111, and basically perform the

20 same processing as the processing region setting unit 10001,
the continuity setting unit 10002, the actual world
estimating unit 10003, image generating unit 10004, image
display unit 10005, and user I/F 10006. Further, in Fig.
147, the actual world estimating unit 15153 comprises a

25 model generating unit 15161, an equation generating unit

15162, and actual world waveform estimating unit 15163. The model generating unit 15161, equation generating unit 15162, and actual world waveform estimating unit 15163 correspond to each of the model generating unit 10011, equation

5　generating unit 10012, and actual world waveform estimating unit 10013 in Fig. 111, and basically perform the same functions as each of the model generating unit 10011, equation generating unit 10012, and actual world waveform estimating unit 10013.

10　　　Note however, that in Fig. 147, the assisting information which the user I/F 15156 outputs by the user operating the user I/F 15156, is supplied only to the equation generating unit 15162.

　　　In other words, in Fig. 147, by operating the user I/F

15　15116, with the equation generating unit 15162, the user can set the constraint conditions which constrain the relation between each of the pixels of an image with no movement blurring, which is an image of the actual world 1 corresponding to the input image and the weighting as to the

20　constraint condition thereof, and when the user performs an operation to set the constraint conditions or an operation to set the weighting, the user I/F 15156 supplies the constraint condition information expressing the constraint conditions set by the operation or the weighting as to the

25　constraint condition to the equation generating unit 15162.

Specifically, for example, a user who views an image displayed on the image display unit 15155 reflecting a blurring image guesses the original image, that is to say, an image without movement blurring which is an image of the

5   actual world 1 corresponding to the input image. Also, for example, the user guesses predetermined regions where blurring is occurring as the edge portions, and guesses the relation of the pixel values between each of the pixels (the constraint conditions), such as the difference being large

10 between the pixel values (level) between the adjacent pixels at the edge portions. Further, the user can set the conditions suitable for the guessed relation of the pixels value between each of the pixels into the equation generating unit 15162, by operating the user I/F 15156.

15   Also, in Fig. 147, the processing region information, which is supplied from the processing region setting unit 15151 to the actual world estimating unit 15153, is supplied to the model generating unit 15161 and the equation generating unit 15162 of the actual world estimating unit

20 15153. The model generating unit 15161 and the equation generating unit 15162 recognize the processing region in the input image from the processing region information supplied from the processing region setting unit 15151.

The continuity setting unit 15152 sets a movement

25 amount (movement vector) v in the input image as the

continuity information that an object is moving in the

horizontal direction of the image at the constant speed of v

pixels per shutter time, and supplies this movement amount v

as the continuity information to the model generating unit

5   15161 of the actual world estimating unit 15153.

The model generating unit 15161 generates an equation

(hereafter referred to as model equation as appropriate) as

a model (hereafter referred to as relation model as

appropriate), modeling the relation between the signal of

10   the actual world 1 and the pixel values of each of the

pixels of the movement blurring image as the input image

which considers the movement amount v as the continuity

information supplied from the continuity setting unit 15152,

regarding the processing region recognized by the processing

15   region information which is supplied from the processing

region setting unit 15151, and supplies the generated model

equation to the equation generating unit 15162.

The equation generating unit 15162 generates a

constraint condition Expression (hereafter referred to as

20   constraint condition expression as appropriate), based on

the constraint condition information supplied from the user

I/F 15156. Also, the equation generating unit 15162 sets

the weighting supplied from the user I/F 15156 into the

constraint condition expression and the model equation

25   supplied to the equation generating unit 15162 by the model

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generating unit 15161, and substitutes the pixel values of
each of the pixels of the input image comprising the
processing region into the equation formed from the weighted
constraint condition expression and the model equation, and

5   thus, generates an equation to find the approximation
function as a model (hereafter referred to as approximation
model) wherein the signal of the actual world 1 is modeled,
and supplies this to the actual world waveform estimating
unit 15163.

10   The actual world waveform estimating unit 15163
estimates the waveform of the actual world 1 signal, by
computing the equation supplied from the equation generating
unit 15162. In other words, the actual world waveform
estimating unit 15163 finds the approximation function as an

15   approximation model, and supplies the approximation function
to the image generating unit 15154 as the estimation result
of the signal waveform of the actual world 1. Note that
approximation function approximating the actual world 1
signals include functions with constant function values,

20   regardless of argument value.
     The image generating unit 15154 recognizes the
processing region in the input image, based on the
processing region information supplied from the processing
region setting unit 15151. Also, the image generating unit

25   15154 generates a signal more closely approximating the

signal of the actual world 1, from the approximation function supplied from the actual world waveform estimating unit 15163, that is to say, generates an image with no movement blurring, and replaces the image of the processing

5   region of the input image with an output image wherein the image has no movement blurring, generates this as an output image, and supplies this to the image display unit 15155.

Next, the processing of the signal processing device 4 in Fig. 147 will be described with reference to the

10   flowchart in Fig. 148.

First, in step S15211, the signal processing device 4 performs pre-processing, and the flow proceeds to step S15212. That is to say, the signal processing device 4 supplies one frame or one field, for example, of the input

15   image, supplied from the sensor 2 (Fig. 1) as data 3, to the processing region setting unit 15151, continuity setting unit 15152, actual world estimating unit 15153, image generating unit 15154, and image display unit 15155. Further, the signal processing unit 4 causes the image

20   display unit 15155 to display the input image.

In step S15212, the user I/F 15156 determines whether or not there has been some sort of user input, by the user operating the user I/F 15156. In step S15212, in the event that determination is made that there is no user input, i.e.,

25   in the event that the user has made no operations, the flow

skips steps S15213 through S15215, and proceeds to step S15216.

On the other hand, in step S15212, in the event that determination is made that there has been user input, i.e., in the event that the user has viewed the input image displayed on the image display unit 15155 and operated the user I/F 15156, thereby making user input indicating some sort of instruction or information, and in the event that there has been some sort of user input, the flow proceeds to step S15213, where the user I/F 15156 determines whether or not the user input is user instructions instructing ending of the processing of the signal processing device 4.

In the event that determination is made that in step S15213 that the user input is ending instructions, the signal processing device 4 ends the processing.

On the other hand, in the event that determination is made in step S15213 that the user input is not ending instructions, the flow proceeds to step S15214, where the user I/F 15156 determines whether or not the user input is constraint condition information or weighting. In the event that determination is made in step S15214 that the user input is not constraint condition information nor weighting, step S15215 is skipped, and the flow proceeds to step S15216.

Also, in step S15214, in the event that the user input is determined to be constraint condition information or

weighting, the flow proceeds to step S15215, and the user
I/F 15156 supplies the constraint condition information or
weighting to the equation generating unit 15162, and the
flow proceeds to step S15216. With the user I/F 15156, both
5   the constraint condition information and the weighting can
be input, and in the event that the user inputs both the
constraint condition information and the weighting, the user
I/F 15156 supplies both the constraint condition information
and the weighting to the equation generating unit 15162.

10   In step S15216, the processing region setting unit
15151 sets the processing region based on the input image,
and supplies the processing region information identifying
the processing region to the continuity setting unit 15152,
the model generating unit 15161 and equation generating unit
15   15162 of the actual world estimating unit 15153, and image
generating unit 15154, and the flow proceeds to step S15217.
Now, an arrangement maybe made wherein the setting of the
processing region in step S15216 is performed by the user
inputting processing region instruction information by
20   operating the user I/F 15156, so as to be carried out based
on the processing region instruction information, or, this
may be carried out without processing region instruction
information from the user.

In step S15217, the continuity setting unit 15152
25   recognizes the processing region in the input image, from

the processing region information supplied from the
processing region setting unit 15151. Further, the
continuity setting unit 15152 sets the continuity of the
actual world 1 signals of which a portion of the continuity

5   is lost in the processing region image data, and supplies
continuity information representing the continuity for the
processing region to the model generating unit 15161 of the
actual world estimating unit 15153, and the flow proceeds to
step S15218. Here, the continuity setting unit 15152 sets

10   the movement amount v, expressing that the movement is in
the horizontal direction at a constant speed of v pixels per
shutter time (exposure time), as the continuity information,
and supplies this to the model generating unit 15161 of the
actual world estimating unit 15153. Here, the continuity

15   setting unit 15152 sets the movement amount showing only the
movement size as continuity information, under the premise
that the object is moving in a horizontal direction, but a
movement vector showing the size and direction of the
movement of the object can be set as continuity information

20   as well. The setting of continuity in step S15217 can be
arranged by the user inputting the continuity instruction
information by operating the user I/F 15156, and can be
performed based on this continuity instruction information,
or can be performed with no continuity instruction

25   information from the user.

The actual world estimating unit 15153 performs actual

world estimating processing in step S15218. In other words,

with the actual world estimating unit 15153, the model

generating unit 15161 generates an equation (model equation)

5   as the model (relation model) wherein the relation of the

pixel values of each of the pixels of the input image which

has movement blurring and the signal of the actual world 1

is modeled, based on the movement amount v supplied from the

continuity setting unit 15152 in step S15217 and the

10   processing region information supplied from the processing

region setting unit 15151 in step S15216, and the generated

model equation is supplied to the equation generating unit

15162.

The equation generating unit 15162 generates a

15   constraint condition expression based on the constraint

condition information supplied from the user I/F 15156 in

step S15215, and sets the weighting supplied from the user

I/F 15156 into the generated constraint condition expression

and into the model equation supplied from the model

20   generating unit 15161 to the equation generating unit 15162.

Also, the equation generating unit 15162 substitutes the

pixel values of each of the pixels of the input image into

an equation formed from the weighted constraint condition

expression and the model equation, and thus generates an

25   equation for finding the approximation function as the model

(approximation model) wherein the signal of the actual world 1 is modeled, and supplies this to the actual world waveform estimating unit 15163. In the event that the user has not specified (set) constraint condition information, that is to

5   say, in the event that NO is determined to be the case in steps S15212 or S15214, the equation generating unit 15162 performs predetermined processing such as a method for solving a simultaneous equation formed of a model equation and an equation hypothesizing that the edge portion of the

10   processing region is "flat", as described in the embodiment in Fig. 113.

Now, the weighting can be set for the model equation only, for the constraint condition expression only, or for both the constraint condition expression and the model

15   equation.

The actual world waveform estimating unit 15163 estimates the waveform of the actual world 1 signal, that is to say, obtains an approximation function approximating the actual world 1 signals by solving the equation supplied from

20   the equation generating unit 15162, and supplies the approximation function to the image generating unit 15154, as estimation results of the waveform of the actual world 1 signals.

The details of the actual world estimating process of

25   step S15218 will be described later with reference to Fig.

150.

After the processing in step S15218, the flow proceeds to step S15219, and the image generating unit 15154 generates a signal more closely approximating the signal of
5   the actual world 1, from the approximation function supplied from the actual world waveform estimating unit 15163, that is to say, generates an image with no movement blurring, and based on the processing region information supplied from the processing region setting unit 15151, replaces the portion
10 of the processing region of the input image with an image which has no movement blurring generated, generates this as an output image, and supplies this to the image display unit 15155, and the flow proceeds to step S15220.

In step S15220, the image display unit 15155 displays
15 the output image supplied from the image generating unit 15154 instead of the input image displayed in step S15211, or along with the input image, and the flow proceeds to step S15221.

In step S15221, as with the case of step S15212, the
20 user I/F 15156 determines whether or not there has been some sort of user input by the user operating the user I/F 15156, and in the event that determination is made that there has been no user input, i.e., in the event that the user has made no operations, the flow returns to step S15221, and
25 awaits some sort of user input.

Also, in the event that determination is made in step S15221 that there has been user input, i.e., in the event that the user has viewed the input image or output image displayed on the image display unit 15155 and operated the user I/F 15156, thereby making user input representing some sort of instructions or information, the flow proceeds to step S15222, where the user I/F 15156 determines whether or not the user input is ending instructions instructing ending of the processing of the signal processing device 4.

In the event that determination is made in step S15222 that the user input is ending instructions, the signal processing device 4 ends the processing.

On the other hand, in the event that determination is made in step S15222 that the user input is not ending instructions, the flow proceeds to step S15223, where the user I/F 15156 determines whether or not the user input is constraint condition information or weighting. In the event that determination is made in step S15223 that the user input is not constraint condition information nor weighting, the flow returns to step S15221, and hereafter the same processing is repeated.

Also, in the event that determination is made in step S15223 that the user input is constraint condition information or weighting, the flow returns to step S15215, and as described above, the user I/F 15156 supplies the

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constraint condition information or weighting to the
equation generating unit 15162. Then the flow proceeds from
step S15215 to S15216, and hereafter the same processing is
repeated. Now, in the event that the signal processing

5   device 4 repeats the processing of step S15215 through step
S15223, the processing of the above-described step S15216
and S15217 are the same as that set by the first processing
S15216 and S15217, and the same process as the first process
may be repeated, or may be skipped.

10   Thus, with the signal processing device 4 in Fig. 147,
by finding an approximation function as a model wherein the
signal of the actual world 1 is modeled, an output image of
high image quality with no movement blurring can be
generated.

15   Also, by operating the user I/F 15156, the user can set
constraint conditions which constrain the relation between
each of the pixels in the original image having no movement
blurring, and in the event that a new constraint condition
is input, an image without movement blurring can be

20   requested again, and therefore an output image of high image
quality according to the preference of the user can be
easily acquired.

In the signal processing device 4 in Fig. 147, an
output image without movement blurring is generated by

25   finding an approximation function which approximates the

light signal of the actual world 1, but this output image

can be regarded as having the movement blurring removed from

the input image. Accordingly, it can be said that

processing is performed for movement blurring removal with

5   the signal processing device 4 in Fig. 147.

Next, the internal configuration of the actual world

estimating unit 15153 in Fig. 147 will be described with

reference to Fig. 149. With the embodiment in Fig. 147 also,

the mechanism for generating movement blurring of objects

10   reflecting in the input image is modeled as a relation of

the above-described Expression (141), which is an example

shown in Figs. 125 and 126.

In other words, let us say that the mechanism for

movement blurring generating is modeled assuming that the

15   pixel values of each of the pixels of the movement blurring

image as the input image are values wherein the pixel values

(or the electric charge corresponding thereto) of each of

the pixels of an image with no movement blurring which are

accumulates (integrated) while moving at the movement amount

20   v.

The actual world estimating unit 15153 comprises a

·model generating unit 15161, an equation generating unit

15162, and an actual world waveform estimating unit 15163.

Further, the equation generating unit 15162 comprises a

25   constraint condition setting unit 15171, a weighting

changing unit 15172, and a normal equation generating unit 15173.

The movement amount v as the continuity information is supplied to the model generating unit 15161 by the

5   continuity setting unit 15152. The movement amount v in this example expresses the continuity of the object moving in the horizontal direction at a constant speed of v pixels per shutter time, within the processing region of the input image which is set by the processing region setting unit

10   15151, and for example, let us say that v = 4, as with the above-described example. Also, the movement amount v can be a value which differs for each line, and in the event that the movement amount v differs for each line, k number, equal to the number of lines, of the movement amount v is supplied

15   as continuity information from the continuity setting unit 15152 to the model generating unit 15161.

Also, processing region information which specifies the processing region within the input image is also supplied to the model generating unit 15161 from the processing region

20   setting unit 15151. In the case of using a rectangular-shaped region as the processing region, the processing region information can be expressed, for example, by coordinate values at opposite angles of a rectangular-shaped processing region as to an absolute coordinates system

25   wherein a predetermined position (pixel) of the input image

is the origin, or the center coordinate of the processing region and the width (horizontal direction) and the height (vertical direction) of the processing region, or the like.

The model generating unit 15161 acquires, for example, a processing region width of 1, and k line numbers, as illustrated in Fig. 119, from the processing region information supplied from the processing region setting unit 15151. In this example, let us say that the processing region 15042 is rectangular-shaped, and for example, has 1 = 10 and k = 4. In this case, the processing region width of each line (the number of pixels) are the same, but with the processing region 15042, each line can have a different processing region width. In the case that the processing region width 1 differs for each line, the model generating unit 15021 acquires k, which is hew same number as the number of lines of the processing region width 1.

Also, the model generating unit 15161 generates an equation (model equation) of a mixed pixel value P_i which is shown in the above-described Expression (141), based on the movement amount v supplied from the continuity setting unit 15152 and the processing region width 1 and k number of lines acquired from the processing region information, and supplies this to the normal equation generating unit 15173.

The constraint condition information specified by the user operating the user I/F 15156 is supplied to the

constraint condition setting unit 15171 from the user I/F

15156. For example, the user performs an operation with the

user I/F 15156 to select (specify) the desired constraint

condition from the constraint conditions which constrain the

5   relation of the pixel values Q_h of each of the pixels of an

image with no movement blurring, such as the above-described

Expression (143) or Expression (144), which have been set in

advance inside the constraint condition setting unit 15171,

and the user I/F 15156 supplies the information describing

10   the selected constraint conditions as the constraint

condition information to the constraint condition setting

unit 15171.

    The constraint condition setting unit 15171 selects a

constraint condition expression corresponding to the

15   constraint condition information supplied from the user I/F

15156 from the constraint condition expressions within the

constraint condition setting unit 15171 itself. Further,

the constraint condition setting unit 15171 acquires the

processing region width l based on the processing region

20   information of the input image supplied to the equation

generating unit 15162 from the processing region setting

unit 15151, and generates only the number which corresponds

to the processing region width l, of he constraint condition

expressions. For example, in the event that Expression

25   (143) is used which has the condition "adjacent pixel

difference = 0" as the constraint condition information, the
constraint condition setting unit 15171 generates the
constraint condition expression expressed by the above-
described Expression (145), by acquiring the processing

5   region width 1 based on the processing region information
supplied from the processing region setting unit 15151, and
supplies this to the normal equation generating unit 15173.
In the example of the processing region 15042 illustrated in
Fig. 119, the processing region 15042 is rectangular-shaped,

10 and the processing region width 1 is the same of each line,
but in the case that the processing region width 1 differs
for each line, the number of constraint condition
expressions also differ for each line.

The weighting changing unit 15172 has a weighting W_{mi}

15 (hereafter will be referred to simply as weighting W_{mi}) as to
the equation for each of the mixed pixel values P_i (the
model equation) and a weighting W_{bj} (hereafter will be
referred to simply as weighting W_{bj}) as to the constraint
condition expression. The values for each of the weighting

20 W_{mi} and the weighting W_{bj} are supplied from the user I/F
15156 by the user operating the user I/F 15156, and are
changed from the default value (for example, 1). In other
words, the user can decide (set) each of the values for the
weighting W_{mi} and the weighting W_{bj}, by operating the user

25 I/F 15156. The weighting changing unit 15172 supplies each

of the weighting W_{mi} and the weighting W_{bj}, set by the user, to the normal equation generating unit 15173, and sets (changes) the weighting of the expressions corresponding to each of the model equation and the constraint condition

5 expression of the normal equation generating unit 15173.

Specifically, with the normal equation generating unit 15173, the weighting W_{bj} is set by the weighting changing unit 15172, as to Expression (147) which considers the error e_{bj} in the constraint condition Expression (145) which is

10 supplied from the constraint condition setting unit 15171. In other words, Expression (147) is changed to Expression (161) which has multiplied both sides thereof by the weighting W_{bj}.

Also, with the normal equation generating unit 15173,

15 the weighting W_{mi} is set by the weighting changing unit 15172, as to Expression (146) which considers the error e_{mi} in the equation for mixed pixel value P_i (model equation) (141) which is supplied from the model generating unit 15161. In other words, Expression (146) is changed to the above-

20 described Expression (162) which has multiplied both sides thereof by the weighting W_{mi}.

The normal equation generating unit 15173 selects one predetermined line from the processing region 15042 as the line of interest, as illustrated in Fig. 128. Then the

25 normal equation generating unit 15173 generates the normal

equation expressed in the above-described Expression (163) from Expression (161) and Expression (162), corresponding to the selected line of interest.

Here, Expression (163) is replaced with Expression (164), using the matrix A'' and the column vectors x, y, e''. In this case, the total sum E'' of the squared errors of the error e_{bj} of Expression (161) and the error e_{mi} of Expression (162) can be expressed with Expression (165), and in order to find the Q_h which causes the total sum E'' of the squared errors to be the minimum, the column vector x (the column vector x with the pixel value Q_h as a component thereof) can be expressed with Expression (166), similar to the above-described Expressions (150) and (151).

Accordingly, the normal equation generating unit 15173 computes the matrix $(A''^{T}A'')^{-1}A''^{T}$, which is a coefficient of the column vector y of the right side of Expression (166), and substitutes the mixed pixel value P_i which is acquired based on the input image supplied from the sensor 2 (Fig. 1) into the column vector y. The matrix $(A''^{T}A'')^{-1}A''^{T}$ is computed, and Expression (166) into which the mixed pixel value P_i is substituted is supplied from the normal equation generating unit 15173 to the actual world waveform estimating unit 15163.

When the processing such as described above is finished wherein one predetermined line of the processing region

15042 is selected as the line of interest, the normal

equation generating unit 15173 selects a line not yet

selected as the next line of interest, and similar

processing is performed as to the selected next line of

5   interest.

The actual world waveform estimating unit 15163, by

computing Expression (166) which is supplied from the normal

equation generating unit 15173, finds the column vector x,

that is to say, the pixel value Q_h with no movement blurring,

10 and supplies this to the image generating unit 15154 (Fig.

147).

The image generating unit 15154 replaces a portion of

the processing region 15042 of the input image with the

image of the pixel value Q_h with no movement blurring, which

15 is supplied from the actual world waveform estimating unit

15163, based on the processing region information supplied

from the processing region setting unit 15151, and generates

this as an output image, and supplies this to the image

display unit 15155.

20 Next, the actual world estimating processing of the

actual world estimating unit 15153 in step S15218 in Fig.

148 will be described with reference to the flowchart in Fig.

150.

First, in step S15251, the model generating unit 15161

25 acquires the processing region width 1 and the number of

lines k, based on the processing region information supplied from the processing region setting unit 15151, and the flow proceeds to step S15252.

In step S15252, the model generating unit 15161
5   acquires k movement amounts v, k being equivalent to the number of lines in the processing region 15042, from the continuity setting unit 15152, and the flow proceeds to step S15253.

In step S15253, the model generating unit 15161
10   generates an equation for the mixed pixel value P_i for each line, and the flow proceeds to step S15254. In other words, the model generating unit 15161 generates k number of model equations (Expression (141)).

In step S15254, the constraint condition setting unit
15   15171 selects the constraint condition expression corresponding to the constraint condition information supplied from the user I/F 15156, from the constraint condition expressions existing within the constraint condition setting unit itself. Also, the constraint
20   condition setting unit 15171 acquires the processing region width l from the processing region information of the input image which is supplied from the equation generating unit 15162 from the processing region setting unit 15151, and generates an constraint condition Expression (Expression
25   (145)) corresponding to the constraint condition information

from the user I/F 15156, which comprises the number of
equations corresponding to the processing region width l,
and the flow proceeds to step S15255.

In step S15255, the weighting changing unit 15172 sets

5 the weighting of each expression of the mixed pixel value P_i
which is supplied from the model generating unit 15161 (the
model equation) and the constraint condition expression
which is supplied from the constraint condition setting unit
15171, by supplying the weighting W_{bj} and the weighting W_{mi}

10 which are supplied from the user I/F 15156 to the normal
equation generating unit 15173, and the flow proceeds to
step S15256.

In step S15256, the normal equation generating unit
15173 selects one predetermined line from the processing

15 region 15042 as the line of interest, and the flow proceeds
to step S15257. In step S15257, the normal equation
generating unit 15173 generates a normal equation expressed
by Expression (163) (Expression (164)) from the constraint
condition Expression (161) wherein the weighting W_{bj} is

20 changed by the weighting changing unit 15172 as to step
S15255, in Expression (145) supplied from the constraint
condition setting unit 15171 and Expression (162) wherein
the weighting W_{mi} is changed by the weighting changing unit
15172 in step S12522 as to Expression (146) considering the

25 error e_{mi} of each of the expressions of the mixed pixel value

Pi expressed by Expression (141) supplied from the model generating unit 15161, and the flow proceeds to step S15258.

In step S15258, the normal equation generating unit 15173 computes the matrix $(A"^T A")^{-1} A"^T$, which is a coefficient of the column vector y of the right side of Expression (166), and the flow proceeds to step S15259.

In step S15259, the normal equation generating unit 15173 substitutes the mixed pixel value P_i which is acquired based on the input image supplied from the sensor 2 (Fig. 1) into the column vector y, and the flow proceeds to step S15260.

In step S15260, the actual world waveform estimating unit 15163 computes a normal equation. That is to say, the actual world waveform estimating unit 15163 finds a pixel value Q_h with no movement blurring by computing Expression (166) which is supplied from the normal equation generating unit 15173, and the flow proceeds to step S15261.

In step S15261, determination is made as to whether or not processing is performed to find a pixel value Q_h with no movement blurring as to all lines of the processing region 15042. In the event that it is determined that processing is not performed to find a pixel value Q_h with no movement blurring as to all lines of the processing region 15042, the process is returned to step S15256, and the processing in steps S15256 through S15261 is repeated. That is to say, a

line not yet selected of the processing region 15042 is

selected as the next line of interest, and processing is

performed to find a pixel value Q_h with no movement blurring.

On the other hand, in the event that it is determined

5   that processing is performed to find a pixel value Q_h with

no movement blurring as to all lines of the processing

region 15042, the actual world estimating processing ends

and returns.

Thus, by generating a normal equation (Expression

10   (163)) as to one line which is taken as the line of interest

of the processing region 15042, and repeating the processing

to find a pixel value Q_h with no movement blurring k number

of times, which is the number of lines in the processing

region 15042, the pixel value Q_h with no movement blurring

15   can be found across the entire region of the processing

region 15042.

Here, in the event that the movement amount v and

processing region width l for each line of the processing

region 15042 are each the same, and that the weighting W_{bj}

20   and the weighting W_{mi} supplied from the user I/F 15156 to the

weighting changing unit 15172 is set (supplied) similarly

with each line of the processing region 15042, the matrix A

of Expression (163) becomes the same for each line.

Accordingly, the matrix $(A''^T A'')^{-1} A''^T$ of Expression (166)

25   becomes the same for each line, and so the processing for

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computing the matrix $(A''^T A'')^{-1} A''^T$ for each line can be
omitted.

Thus, the actual world estimating processing of the
actual world estimating unit 15153 in step S15218 in Fig.

5   148, in the event that the movement amount v and processing
region width l for each line of the processing region 15042
are each the same, and that the weighting W_{bj} and the
weighting W_{mi} supplied from the user I/F 15156 to the
weighting changing unit 15172 is set (supplied) similarly

10   with each line of the processing region 15042, will be
described with reference to the flowchart in Fig. 151. Now,
with regard to the portions in Fig. 151 which are similar to
the flowchart in Fig. 150, the description thereof will be
omitted as appropriate.

15   In Fig. 151, the processing of step S15288
corresponding to step S15256 in Fig. 150 is not positioned
between steps S15285 and S15286, but rather between steps
S15287 and S15289. Further, in step S15291, in the event
that it is determined that the processing for finding the

20   pixel value Qh without movement blurring is not performed as
to all of the lines in the processing region 15042, the
processing returns the flow to step S15288.

In other words, in the event that the movement amount v
and processing region width l for each line of the

25   processing region 15042 are each the same, and that the

weighting W_{bj} and the weighting W_{mi} supplied from the user I/F 15156 to the weighting changing unit 15172 is set (supplied) similarly with each line of the processing region 15042, the normal equation generated in step S15286 becomes

5   the same for each line, and therefore, after computing the matrix $(A''^T A'')^{-1} A''^T$ as to the first line of interest in step S15287, computing the matrix $(A''^T A'')^{-1} A''^T$ (the processing in step S15287) as to the line of interest hereafter is not necessary. Accordingly, the selection of the line of

10 interest (step S15288), the substitution of the mixed pixel value P_i (the processing in step S15289), and the computing of the normal equation (the processing in step S15290) need only be executed in order, as to the lines in the processing region 15042 which have not yet been selected.

15   Thus, with the embodiment illustrated in Fig. 147, a normal equation is generated from the equation of the mixed pixel value P_i wherein the pixel value with movement blurring occurring is modeled with a pixel value with no movement blurring, and the constraint condition expression

20 using the relation between the adjacent pixels of the pixel values with no movement blurring, and by computing this normal equation, a pixel value with no movement blurring can be found, and thus an image with good image quality can be generated.

25   Also, the weighting for each of the mixed pixel value P_i

equation and constraint condition expression is supplied to

the signal processing device 4 and set as desired values by

the user operating the user I/F 15156, and therefore, an

image of high image quality according to the preference of

5   the user can be generated.

In the above-described example, the information showing

which constraint condition the user selected (specified)

from the several constraint conditions previously set inside

the constraint condition setting unit 15171 is used as the

10   constraint condition information supplied from the user I/F

15156 to the constraint condition setting unit 15171, but

the user may also directly input the constraint condition

expression by operating the user I/F 15156.

Also, in addition to the above-described embodiment,

15   with the constraint condition setting unit 15171, the

predetermined constraint conditions are determined (fixed),

the user can operate the user I/F 15156 to select the

constraint conditions, or use an embodiment wherein directly

inputting the constraint condition expression is not

20   necessary.

Now, with the continuity setting unit 15012 in Fig. 113

(similar with other continuity setting units), the movement

as the continuity information can be set based on the user

operation, but also can be set by detecting the movement

25   from the input image.

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The detecting method of the movement with the continuity setting unit 15012 in Fig. 113 will be described.

In the event that a certain object is moving in an input image, as for a method for detecting movement vector

5   serving as the movement of the object for example, the so-called block matching method has been known.

However, with the block matching method, matching is performed between the frame of interest and the frames before and after the frame of interest, so that movements

10 cannot be detected easily with the frame of interest alone.

To this end, the continuity setting unit 15012 is configured so as to detect movements from an input image having one frame alone.

Fig. 152 illustrates a configuration example of the

15 continuity setting unit 15012 in Fig. 113.

With the continuity setting unit 15012 of which the configuration is shown in Fig. 152, the movement direction of an object in the processing region of the an input image is detected, and the input image is corrected such that the

20 movement direction becomes the horizontal direction. Subsequently, the features subjected to the one-dimensional differentiation in the movement direction of the object in the input image, which are the differential value of the pixel values of pixels adjacent in the movement direction,

25 are detected.

Further, the correlation is detected between the features of the pixel of interest and the features of the corresponding pixel with a predetermined distance in the movement direction, and the movement amount of the object is detected according to the distance between the corresponding pixel and the pixel of interest, which exhibits the maximum detected correlation.

The continuity setting unit 15012 of which the configuration is shown in Fig. 152 includes a movement direction detecting unit 11201, a movement direction correcting unit 11202, a features detecting unit 11203, and a movement amount detecting unit 11204.

Further, the movement direction detecting unit 11201 includes an activity computing unit 11211, and an activity evaluating unit 11212. The movement direction correcting unit 11202 includes an affine transformation unit 11213.

The features detecting unit 11203 includes a difference computing unit 11214, a difference evaluating unit 11215, an intermediate image creating unit 11216, an intermediate image creating unit 11217, frame memory 11218, a sign inverting unit 11219, and frame memory 11220.

Further, the movement amount detecting unit 11204 includes a correlation detecting unit 11221, and a correlation evaluating unit 11222.

With the continuity setting unit 15012 wherein the

configuration is illustrated is Fig. 152, the input image is
supplied to the movement direction detecting unit 11201 and
the movement direction correcting unit 11202. Further, the
processing region information that is output from the

5   processing region setting unit 15011 in Fig. 113 is also
supplied to the movement direction detecting unit 11201 and
the movement direction correcting unit 11202.

The movement direction detecting unit 11201 acquires
the input image and the processing region information, and

10   detects the movement direction in the processing region from
the acquired input image.

When capturing a moving object, movement blurring
occurs on the image of the object. This is caused by
actions of the image sensor of a camera or video camera

15   serving as the sensor 2 for capturing the image of an object.

That is to say, an image sensor such as a CCD (Charge
Coupled Device) or CMOS (Complementary Metal-Oxide
Semiconductor) sensor consecutively converts the incident
light into electric charge for each pixel during exposure

20   time (shutter time), and further converts the electric
charge into one pixel value. When an object to be captured
is in a stationary state, the image (light) of the same
portion of the object is converted into one pixel value
during exposure time. The image thus captured includes no

25   movement blurring.

On the other hand, when an object is moving, the image of the portion of the object to be cast into one pixel changes during exposure time, and the images of different portions of the object are converted into one pixel value by

5 accident. Speaking inversely, the image of one portion of the object is cast into multiple pixel values, which is movement blurring.

Movement blurring occurs in the movement direction of the object.

10 Upon focusing on the pixel values of pixels arrayed in the movement direction of the portion where movement blurring occurs (region including movement blurring), the image of generally the same range portion of the object is projected to the pixel values of the pixels arrayed in the

15 movement direction. Accordingly, we can say that change in the pixel values of the pixels arrayed in the movement direction at the portion where movement blurring occurs is further reduced.

The movement direction detecting unit 11201 detects a

20 movement direction based on such change, i.e., activity in the pixel value of a pixel in the processing region of an input image.

More specifically, the activity computing unit 11211 of the movement direction detecting unit 11201 computes change

25 (activity) in the pixel values of pixels arrayed in various

directions for each predetermined direction. For example, the activity computing unit 11211 computes the difference between the pixel values of the pixels positioned corresponding to each direction for each predetermine

5   direction as activity. The activity computing unit 11211 supplies information indicating change in the computed pixel values to the activity evaluating unit 11212.

The activity evaluating unit 11212 selects the minimum change in the pixel value, of change in the pixel values of

10 the pixels for each predetermined direction supplied from the activity computing unit 11211, and takes the direction corresponding to the selected change in the pixel value as the movement direction.

The movement direction detecting unit 11201 supplies

15 movement direction information indicating the movement direction thus detected to the movement direction correcting unit 11202.

The movement direction correcting unit 11202 is supplied with processing region information as well. The

20 movement direction correcting unit 11202 converts the image data within the processing region in the input image based on the movement direction information supplied from the movement direction detecting unit 11201 such that the movement direction becomes the horizontal direction of the

25 image.

For example, the affine transformation unit 11213 of the movement direction correcting unit 11202 subjects the image data within the processing region in the input image to affine transformation based on the movement direction

5   information supplied from the movement direction detecting unit 11201 such that the movement direction shown in the movement direction information becomes the horizontal direction of the image.

The movement direction correcting unit 11202 supplies

10   the image data within the processing region in the input image converted such that the movement direction becomes the horizontal direction of the image to the features detecting unit 11203.

Now, with the input image, the hypothesis is that the

15   object is moving in the horizontal direction (from the left to the right direction), and therefore the continuity setting unit 15012 can be configured without providing the movement direction detecting unit 11201 and the movement direction correcting unit 11202.

20   The features detecting unit 11203 detects the features of the image supplied from the movement direction correcting unit 11202.

That is to say, the difference computing unit 11214 of the features detecting unit 11203 sets a pixel selected by

25   selecting one pixel from the pixels in the processing region

of the input image, as a pixel of interest. Subsequently, the difference computing unit 11214 of the features detecting unit 11203 obtains a difference value by subtracting the pixel value of the pixel adjacent to the

5   pixel of interest on the right side from the pixel value of the pixel of interest.

The difference computing unit 11214 obtains difference values by taking the pixels in the processing region of the input image as a pixel of interest in order. That is to say,

10 the difference computing unit 11214 obtains difference values regarding all of the pixels in the processing region of the input image. The difference computing unit 11214 supplies the difference values thus computed to the difference evaluating unit 11215 along with information

15 indicating the position of the pixel of interest corresponding to each obtained difference value (positional information indicating the position on the screen of each difference value).

The difference evaluating unit 11215 determines

20 regarding whether or not the difference values are 0 or more, supplies the difference values equal to or greater than 0 to the intermediate image creating unit 11216 along with the positional information indicating the position on the screen of each difference value, and supplies the difference values

25 less than 0 to the intermediate image creating unit 11217

along with the positional information indicating the
position on the screen of each difference value.

The intermediate image creating unit 11216 creates,
based on the difference values equal to or greater than 0

5   supplied from the difference evaluating unit 11215 along
with the positional information indicating the position on
the screen of the difference values, an intermediate image
made up of each difference value. That is to say, the
intermediate image creating unit 11216 creates an

10   intermediate image by setting the difference values equal to
or greater than 0 supplied from the difference evaluating
unit 11215 to the pixels at the positions on the screen
indicated by the positional information, and setting 0 to
the pixels at the positions where no difference value is

15   supplied from the difference evaluating unit 11215. The
intermediate image creating unit 11216 supplies the
intermediate image thus created (hereafter, referred to as
non-inverted intermediate image) to the frame memory 11218.

The intermediate image creating unit 11217 creates,

20   based on the difference values less than 0 (negative values)
supplied from the difference evaluating unit 11215 along
with the positional information indicating the positions on
the screen of the difference values, an intermediate image
made up of the difference values. That is to say, the

25   intermediate image creating unit 11217 creates an

intermediate image by setting the difference values less

than 0 supplied from the difference evaluating unit 11215 to

the pixels at the positions on the screen indicated by the

positional information, and setting 0 to the pixels at the

5   positions where no difference value is supplied from the

difference evaluating unit 11215. The intermediate image

creating unit 11216 supplies the intermediate image thus

created to the sign inverting unit 11219.

The sign inverting unit 11219 inverts the signs of the

10   difference values less than 0 set to the pixels of the

intermediate image supplied from the intermediate image

creating unit 11217. The signs of the value 0 set to the

pixels of the intermediate image are not inverted. That is

to say, the sign inverting unit 11219 selects the difference

15   values less than 0 set to the pixels of the intermediate

image supplied from the intermediate image creating unit

11217, and converts the selected difference values less than

0 into the values greater than 0 having the same absolute

values as the difference values. For example, the

20   difference value, which is -15, is converted into 15 by

inverting the sign thereof. The sign inverting unit 11219

supplies the intermediate image thus sign-inverted

(hereafter referred to as inverted intermediate image) to

the frame memory 11220.

25   The frame memory 11218 supplies the non-inverted

intermediate image made up of the difference values equal to or greater than 0 and 0 to the movement amount detecting unit 11204 as features. The frame memory 11220 supplies the inverted intermediate image made up of the difference values

5   greater than 0 of which the signs are inverted and 0 to the movement amount detecting unit 11204 as features.

The movement detecting unit 11204 detects movements based on the features supplied from the features detecting unit 11203. That is to say, the movement detecting unit

10   11204 detects the correlation between the features of at least the pixel of interest, of the pixels of the image of the object in the processing region of the input image, and the features of the corresponding pixel allocated in the movement direction as to the pixel of interest, and detects

15   the movement amount of the image of the object in the processing region of the input image according to the detected correlation.

The correlation detecting unit 11221 of the movement amount detecting unit 11204 detects the correlation between

20   the non-inverted intermediate image serving as features supplied from the frame memory 11218 of the features detecting unit 11203, and the inverted intermediate image serving as features supplied from the frame memory 11220 of the features detecting unit 11203. The correlation

25   detecting unit 11221 supplies the detected correlation to

the correlation evaluating unit 11222.

More specifically describing, for example, the correlation detecting unit 11221 of the movement amount detecting unit 11204 moves (shifts) the inverted

5   intermediate image made up of the difference values of which the signs are inverted so as to be greater than 0, and 0 supplied from the frame memory 11220 of the features detecting unit 11203, in the horizontal direction of the screen in units of pixel as to the non-inverted intermediate

10 image made up of the difference values equal to or greater than 0, and 0 supplied from the frame memory 11218 of the features detecting unit 11203. That is to say, the correlation detecting unit 11221 moves the positions on the screen of the pixels making up the inverted intermediate

15 image in the horizontal direction.

The positional relation on the screen between the pixels of the non-inverted intermediate image and the pixels of the inverted intermediate image changes by moving (the pixels of) the inverted intermediate image in the horizontal

20 direction on the screen. For example, the corresponding pixel of the inverted intermediate image positioned on the screen corresponding to the pixel of interest of the non-inverted intermediate image before movement results in departing from the position corresponding to the pixel of

25 interest of the non-inverted intermediate image by the

movement distance after movement. More specifically, when the non-inverted intermediate image is moved to the right by 20 pixels, the corresponding pixel of the inverted intermediate image departs from the position corresponding

5   to the pixel of interest of the non-inverted intermediate image to the right by 20 pixels. Speaking inversely, the corresponding pixel of the inverted intermediate image positioned on the screen corresponding to the pixel of interest of the non-inverted intermediate image after

10 movement departs from the position corresponding to the pixel of interest by the movement distance before movement.

The correlation detecting unit 11221 computes the difference between the pixel values of the pixels corresponding to the non-inverted intermediate image and the

15 inverted intermediate image moved, and takes the sum of the differential absolute values as a correlation value.

For example, the correlation detecting unit 11221 moves (shifts) the inverted intermediate image in the horizontal direction of the screen in increments of one pixel in a

20 range of 70 pixels in the left direction of the screen through 70 pixels in the right direction of the screen as to the non-inverted intermediate image, computes the difference between the pixel values of the pixels to be positioned at the same position on the screen regarding the non-inverted

25 intermediate image and the inverted intermediate image moved

for each moved position (each movement distance), and takes the sum of the differential absolute values as a correlation value.

For example, when the inverted intermediate image is

5 moved to the left direction of the screen as to the non-inverted intermediate image, the movement distance is represented with a negative (minus). When the inverted intermediate image is moved to the right direction of the screen as to the non-inverted intermediate image, the

10 movement distance is represented with a positive (plus). The correlation detecting unit 11221 computes the difference between the pixel values of the pixels to be positioned at the same position on the screen regarding the non-inverted intermediate image and the inverted intermediate image moved

15 for each movement distance of -70 pixels through +70 pixels, and takes the sum of the differential absolute values as a correlation value.

The correlation detecting unit 11221 supplies the correlation value corresponding to the movement distance to

20 the correlation evaluating unit 11222. That is to say, the correlation detecting unit 11221 supplies a pair of the movement distance and the correlation value to the correlation evaluating unit 11222.

The correlation evaluating unit 11222 detects the

25 movement amount of the image of the object in the processing

region of the input image according to the correlation.

More specifically, the correlation evaluating unit 11222

takes, of the correlations supplied from the correlation

detecting unit 11221, the movement distance corresponding to

5   the maximum (strongest) correlation as a movement amount.

For example, the correlation evaluating unit 11222

selects the minimum value, of the sum of the differential

absolute values serving as the correlation value supplied

from the correlation detecting unit 11221, and sets the

10   movement distance corresponding to the selected minimum

value to the movement amount.

The correlation evaluating unit 11222 outputs the

detected movement amount.

Fig. 153 through Fig. 155 are diagrams for describing

15   the principle for detecting movements by the continuity

setting unit 15012 in Fig. 152.

Now, let us say that a white foreground object serving

as an object to be captured is disposed in front of a black

background object serving as another object to be captured,

20   and is moving from the left side to the right side, and a

camera having an image sensor such as a CCD or CMOS sensor

captures the foreground object along with the background

object with a predetermined exposure time (shutter time).

In this case, upon focusing on one frame of the image

25   to be output from the camera, the background object is black,

so that the camera outputs, for example, a pixel value 0 as

to the background object image. The foreground object is

white, so that the camera outputs, for example, a pixel

value 255 as to the foreground object image. Note that here,

5   let us say that the camera outputs a pixel value in a range

of 0 through $2^8 - 1$.

The diagram in the upper side of Fig. 153 is a diagram

illustrating the pixel values of the image to be output by

the camera when the foreground object is in a stationary

10   state at the position at the moment that the shutter of the

camera opens (moment of starting exposure).

The diagram in the lower side of Fig. 153 is a diagram

illustrating the pixel values of the image to be output by

the camera when the foreground object is in a stationary

15   state at the position at the moment that the shutter of the

camera closes (moment of ending exposure).

As shown in Fig. 153, the movement amount of the image

of the foreground object is a distance wherein the image of

the foreground object moves from the moment that the shutter

20   of the camera opens until the moment that the shutter of the

camera closes.

Fig. 154 is a diagram illustrating the pixel values of

the image to be output from the camera when the foreground

object moving in front of the background object is captured

25   by the camera. The image sensor of the camera consecutively

converts the image (light) of the object into electric

charge during exposure time (shutter time) for each pixel,

and further converts the electric charge into one pixel

value, and accordingly, the image of the foreground object

5   11251 is projected into the pixel values of the multiple

pixels. The maximum pixel value of the image shown in Fig.

154 is small as compared with the maximum pixel value of the

image shown in Fig. 153.

The slope width of the pixel values shown in Fig. 154

10   corresponds to the width of the image of the background

object.

Upon the difference value as to the adjacent pixel on

the right side being computed, and set to the pixel

regarding each pixel of the image shown in Fig. 154, the

15   image made up of the difference values shown in Fig. 155 is

obtained.

That is to say, one pixel is selected from the pixels

of the image shown in Fig. 154, and set to as a pixel of

interest to which attention is paid. Subsequently, the

20   difference value is obtained by subtracting the pixel value

of the pixel adjacent to the pixel of interest on the right

side from the pixel value of the pixel of interest. The

difference value is set to the pixel at the position

corresponding to the pixel of interest. The pixels of the

25   image shown in Fig. 154 are taken as a pixel of interest in

order, and the image made up of the difference values shown in Fig. 155 is obtained.

The difference value having a negative (minus) sign emerges on the one-pixel left side as to the position of the foreground object at the moment that the shutter of the camera opens shown in the diagram on the upper side of Fig. 153, and the difference value having a positive (plus) sign emerges on the one-pixel left side as to the position of the foreground object at the moment that the shutter of the camera closes shown in the diagram on the lower side of Fig. 153.

Accordingly, upon matching being performed between a value obtained by inverting the sign of the difference value having a negative (minus) sign and the difference value having a positive (plus) sign shown in Fig. 155, the movement distance of the value obtained by inverting the sign of the difference value having a negative (minus) sign is the same as the movement amount on the basis of the difference value having a positive (plus) sign when performing matching, for example.

For example, on the basis of the difference value having a positive (plus) sign, the value obtained by inverting the sign of the difference value having a negative (minus) sign is moved in the horizontal direction, the correlation between the value obtained by inverting the

negative difference value and the positive difference value

is detected for each movement distance thereof, thereby

detecting the maximum (strongest) correlation. The movement

distance when the maximum correlation is detected is the

5   same as the movement amount.

More specifically, for example, on the basis of the

difference value having a positive (plus) sign, the value

obtained by inverting the sign of the difference value

having a negative (minus) sign is moved in the horizontal

10   direction, as the correlation between the value obtained by

inverting the negative difference value and the positive

difference value for each movement distance thereof, the

positive difference value is subtracted from the inverted

value for each pixel. Subsequently, the minimum value

15   within the subtracted results, i.e., the maximum correlation

is detected. The movement distance corresponding to the

detected maximum correlation is the same as the movement

amount.

As described above, the movement amount, which is the

20   amount wherein the image of the object moves, can be

detected from one frame of the image during exposure time

(shutter time).

That is to say, the difference computing unit 11214 of

the features detecting unit 11203 selects one pixel from

25   pixels in the processing region of the input image, sets

this as a pixel of interest, and subtracts the pixel value

of the pixel adjacent to the pixel of interest on the right

side from the pixel value of the pixel of interest, thereby

computing the difference values shown in Fig. 155, for

5   example. The difference evaluating unit 11215 classifies

the difference values into the positive difference values

and the negative difference values based on the signs of the

difference values.

The intermediate image creating unit 11216 creates,

10   from the classified positive difference values, a non-

inverted intermediate image made up of the positive

difference values thereof. The intermediate image creating

unit 11217 creates, from the classified negative difference

values, an intermediate image made up of the negative

15   difference values thereof. The sign inverting unit 11219

creates a non-inverted intermediate image by inverting the

signs of the negative pixel values of the intermediate image

made up of the negative difference values.

The movement amount detecting unit 11204 obtains the

20   movement distance of the non-inverted intermediate image and

the inverted intermediate image, which have the strongest

correlation, and takes the obtained movement distance as the

movement amount.

When the features detecting unit 11203 detects the

25   image of the moving object, and detects the features of the

image of the moving object, the movement amount detecting

unit 11204 detects a correlation based on the features, and

detects the movement amount of the image of the object

within the input image according to the detected correlation.

5   Also, when the features amount detecting unit 11203

selects the pixel of interest to which attention is paid

from the pixels belonged to the image of the moving object,

and detects the features of the pixel of interest, the

movement amount detecting unit 11204 detects the correlation

10   between the features of the pixel of interest and the

features of the corresponding pixel to be allocated in the

movement direction as to the pixel of interest, and detects

the movement amount of the image of the object in the

processing region of the input image according to the

15   detected correlation.

Fig. 156 is a flowchart for describing the processing

for detecting a movement amount by the continuity setting

unit 15012 in Fig. 152.

In step S11201, the movement direction detecting unit

20   11201 and the movement direction correcting unit 11202

acquire the input image and the processing region

information, and the flow proceeds to step S11202.

In step S11202, the activity computing unit 11211 of

the movement direction detecting unit 112011 computes

25   activity regarding the pixels of the processing region in

the input image acquired in the processing in step S11201,
and the flow proceeds to step S11203.

For example, the activity computing unit 11211 selects
the pixel of interest to which attention is paid, of the
pixels of the processing region in the input image. The
activity computing unit 11211 extracts a predetermined
number of perimeter pixels in the vicinity of the pixel of
interest. For example, the activity computing unit 11211
extracts perimeter pixels made up of 5 × 5 pixels (5 pixels
by 5 pixels) centered on the pixel of interest.

Subsequently, the activity computing unit 11211 detects
activity corresponding to the predetermined direction on the
image from the extracted perimeter pixels.

With the following description, a pixel array in the
horizontal direction is referred to as a row, and a pixel
array in the vertical direction is referred to as a column.

Regarding 5 × 5 perimeter pixels for example, the
activity computing unit 11211 detects activity as to the
angle of 90 degrees (vertical direction of the screen) on
the basis of the horizontal direction of the screen by
computing the differences between the pixel values of the
adjacent pixels in the up-and-down (vertical) direction on
the screen, dividing the sum of the differential absolute
values computed by the number of differences, and taking the
result as activity.

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For example, the difference of pixel values is computed
regarding the two pixels adjacent in the up-to-down
direction on the screen of 20 pairs, the sum of the
differential absolute values computed is divided by 20, and
5   the result (quotient) is set to the activity as to the angle
of 90 degrees.

Regarding 5 × 5 perimeter pixels for example, the
activity computing unit 11211 detects activity as to the
angle of 76 degrees $(\tan^{-1} (4/1))$ on the basis of the
10   horizontal direction of the screen by computing the
differences between the respective pixel values of the
leftmost pixel through the fourth pixel from the left in the
lowest row, and the respective pixel values of the pixels on
the four-pixel upper side and also on one-pixel right side
15   as to the respective pixels, dividing the sum of the
differential absolute values computed by the number of
differences, and taking the result as activity.

For example, the difference of pixel values is computed
regarding the two pixels in the upper right direction having
20   a distance of four pixels in the vertical direction, and one
pixel in the horizontal direction of four pairs, the sum of
the differential absolute values computed is divided by four,
and the result (quotient) is set to the activity as to the
angle of 76 degrees.

25   The activity computing unit 11211 detects activity as

to the angle in a range of 90 degrees through 180 degrees on the basis of the horizontal direction of the screen with the same processing. In the event of detecting activity as to the angle in a range of 90 degrees through 180 degrees,

5   activity is calculated based on the difference of the pixel values of the pixels positioned in the upper left direction.

The activity thus detected is taken as the activity as to the pixel of interest.

Note that the detected activity may be the activity as

10   to the perimeter pixels.

Also, description has been made that the perimeter pixels are made up of 5 × 5 pixels (5 pixels by 5 pixels), but pixels having a desired range may be employed regardless of 5 × 5 pixels. In the event of employing a great number

15   of perimeter pixels, angular resolution improves.

The activity computing unit 11211 supplies information indicating activity corresponding to multiple directions to the activity evaluating unit 11212.

Returning to Fig. 156, in step S11203, the activity

20   evaluating unit 11212 obtains the movement direction by selecting the minimum activity based on the activity corresponding to a predetermined direction calculated in the processing in step S11202, and taking the selected direction as the movement direction, and the flow proceeds to step

25   S11204.

In step S11204, the movement direction correcting unit 11202 converts the image data in the processing region of the input image based on the movement direction obtained in the processing in step S11203 such that the movement

5 direction becomes the horizontal direction of the image, and the flow proceeds to step S11205. For example, in step S11204, the affine transformation unit 11213 of the movement direction correcting unit 11202 subjects the image data in the processing region of the input image to affine

10 transformation based on the movement direction obtained in the processing in step S11203 such that the movement direction becomes the horizontal direction of the image. More specifically, for example, the affine transformation unit 11213 subjects the image data in the processing region

15 of the input image to affine transformation so as to rotate 18 degrees in the clockwise direction on the basis of the horizontal direction of the screen when the movement direction is the angle of 18 degrees.

In step S11205, the difference computing unit 11214 of

20 the features detecting unit 11203 computes the difference value of the pixel value as to the pixel adjacent in the horizontal direction regarding each pixel in the processing region of the input image converted such that the movement direction becomes the horizontal direction of the screen in

25 the processing in step S11204, and the flow proceeds to step

S11206.

For example, in step S11205, the difference computing unit 11214 sets a pixel of interest to which attention is paid by selecting one pixel from the pixels in the

5   processing region of the input image. Subsequently, the difference computing unit 11214 obtains the difference value by subtracting the pixel value of the pixel adjacent to the pixel of interest on the right side from the pixel value of the pixel of interest.

10   In step S11206, the difference evaluating unit 11215 of the features detecting unit 11203 allocates the difference values based on the signs of the difference values, and the flow proceeds to step S11207. That is to say, the difference evaluating unit 11215 supplies the difference

15   values equal to or greater than 0 to the intermediate image creating unit 11216, and supplies the difference values less than 0 to the intermediate image creating unit 11217. In this case, the difference evaluating unit 11215 supplies the difference values to the intermediate image creating unit

20   11216 or the intermediate image creating unit 11217 along with the positional information indicating the position of each difference value on the screen.

In step S11207, the intermediate image creating unit 11216 of the features detecting unit 11203 creates an

25   intermediate image made up of the positive difference values

based on the difference values equal to or greater than 0
(positive difference values) allocated in the processing in
step S11206, and the flow proceeds to step S11208. That is
to say, in step S11207, the intermediate image creating unit

5   11216 creates an intermediate image by setting the positive
difference values to the pixels at the positions on the
screen indicated with the positional information, and
setting 0 to the pixels at the positions where no difference
value was supplied.

10   Thus, a non-inverted intermediate image is created in
the processing in step S11207. In step S11208, the
intermediate image creating unit 11217 of the features
detecting unit 11203 creates an intermediate image made up
of the negative difference values based on the difference

15   values less than 0 (negative difference values) allocated in
the processing in step S11206, and the flow proceeds to step
S11209. That is to say, in step S11208, the intermediate
image creating unit 11217 creates an intermediate image by
setting the negative difference values to the pixels at the

20   positions on the screen indicated with the positional
information, and setting 0 to the pixels at the positions
where no difference value was supplied.

In step S11209, the sign inverting unit 11219 of the
features detecting unit 11203 inverts the signs of the

25   negative difference values of the intermediate image made up

of the negative difference values created in the processing

in step S11208. That is to say, in step S11209, the

negative difference values set to the pixels of the negative

intermediate image are converted into the positive values

5 having the same absolute values.

Thus, in step S11209, a non-inverted intermediate image

is created, and then the flow proceeds to step S11210.

In step S11210, the movement amount detecting unit

11204 executes correlation detecting processing. The

10 details of the processing in step S11210 will be described

later with reference to the flowchart in Fig. 157.

In step S11211, the correlation evaluating unit 11222

selects the strongest correlation, of the correlations

detected in the processing in step S11210, and the flow

15 proceeds to step S11212. For example, in step S11211, of

the correlation values serving as the sum of the

differential absolute values of the pixel values, the

minimum correlation value is selected.

In step S11212, the correlation evaluating unit 11222

20 sets the movement distance corresponding to the strongest

correlation selected in the processing in step S11211 to the

movement amount, and the flow proceeds to step S11213. For

example, in step S11212, of the correlation values serving

as the sum of the differential absolute values of the pixel

25 values, the movement distance of the inverted intermediate

image stored in the processing in step S11223 described later corresponding to the selected minimum correlation value is set to the movement amount.

In step S11213, the movement amount detecting unit 11204 outputs the movement amount detected in the processing in step S11210, and the processing ends.

Fig. 157 is a flowchart for describing correlation detecting processing corresponding to the processing in step S11210.

In step S11221, the correlation detecting unit 11221 of the movement amount detecting unit 11204 moves the positions of the pixels of the inverted intermediate image created in the processing in step S11209 in the horizontal direction in increments of pixel, and the flow proceeds to step S11222.

In step S11222, the correlation detecting unit 11221 detects the correlation between the non-inverted intermediate image and the inverted intermediate image of which the positions of the pixels are moved in the processing in step S11221, and the flow proceeds to step S11223. For example, in step S11222, the differences are computed between the pixel values of the pixels of the non-inverted intermediate image and the pixel values of the pixels of the inverted intermediate image at the corresponding positions on the screen, and the sum of the computed differential absolute values is detected as a

correlation value. The correlation detecting unit 11221

supplies correlation information indicating the detected

correlation to the correlation evaluating unit 11222 along

with the movement distance of the pixels of the inverted

5   intermediate image in the processing in step S11221.

In step S11223, the correlation evaluating unit 11222

stores the correlation detected in the processing in step

S11222 along with the movement distance of the pixels of the

inverted intermediate image in the processing in step S11221,

10   and the flow proceeds to step S11224. For example, the

correlation evaluating unit 11222 stores the correlation

value serving as the sum of the differential absolute values

of the pixel values along with the movement distance of the

pixels of the inverted intermediate image in the processing

15   in step S11221.

In step S11224, the correlation detecting unit 11221

determines regarding whether or not correlation as to all of

the movement distances has been detected, and in the event

that determination is made that correlation has not been

20   detected with some movement distances, the flow returns to

step S11221, where the processing for detecting correlation

as to the next movement distance is repeated.

For example, in step S11224, the correlation detecting

unit 11221 determines whether or not all correlations have

25   been detected in a case of moving pixels of the inverted

intermediate image in the range of 70 pixels in the left
direction in the image through 70 pixels in the right
direction in the image.

In the event that determination is made in step S11224
5   that the correlations for all movements amount have been
detected, the processing ends (returns).

Thus, the correlation detecting unit 11221 can detect
correlation.

As described above, the continuity setting unit 15012
10   of which the configuration is shown in Fig. 152 can detect
movement amount from one frame in an image.

Now, while movement has been detected here with regard
to a processing region, an arrangement may be made wherein
movement over the entire screen due to hand shaking, for
15   example, can be detected, by processing the entire screen.

Also, even in the event that there are a great amount
of repetitive patterns of the same design in the input image,
these can be detected in an accurate manner so long as the
movement distance and movement direction of the processing
20   region in the input image to be processed is constant.

While movement amount detection from one frame in an
image has been described above, it is needless to say that
an arrangement may be made wherein movement amount is
detected from one field.

25   Also, an arrangement may be made wherein the movement

amount is detected regarding only the perimeter of the

selected pixel of interest.

The above-described embodiments include, besides

embodiments of the invention described in the Claims,

5   embodiments regarding the first and second signal processing

devices given below.

A first signal processing device comprises: processing

region setting means for setting the processing region

within data, wherein light signals of the real world have

10   been projected on a plurality of pixels each having time

integration effects and a part of the continuity of the real

world light signals has been lost; movement vector setting

means for setting movement vectors of an object within the

image data corresponding to the continuity of the real world

15   light signals of which a part of the continuity has been

lost in the image data; model generating means for modeling

the region between pixel values of each of the pixels within

the processing region and pixel values of each of the pixels

where there is no movement blurring, with the understanding

20   that the pixel values of each of the pixels within the

processing region are values obtained by pixel values of

each of the pixels without movement blurring as to the

object being integrated while moving corresponding to a

movement vector; normal equation generating means for

25   generating normal equations from a first equation wherein

the pixel values of the pixels within the processing region

have been substituted into a model generated by the model

generating means, and a second equation for constraining the

relation between the pixels where there is no movement

5   blurring; activity detecting means for detecting the

activity corresponding to each of the pixels within the

processing region; weight changing means for changing the

weighting as to a part of the first and second equations

according to the detection results by the activity detecting

10   means; and actual world estimating means for estimating the

pixel values of each of the pixels where there is no

movement blurring, by computing the normal equations

generated by the normal equation generating means and of

which the weighting has been changed by the weight changing

15   means.

      With the second signal processing device, in addition

to the features of the first signal processing device, the

weighting changing means change the weighting as to a

portion of the first and second equations, corresponding to

20   the pixel of interest, to zero, when the activity

corresponding to the pixel of interest within the processing

region of the image data is greater than the predetermined

threshold value.

      The above-described embodiments also include

25   embodiments regarding signal processing methods, programs,

and recording mediums, given below.

A signal processing method, program, and recording
medium, comprise: a processing region setting step for
setting the processing region within data, wherein light
5   signals of the real world have been projected on a plurality
of pixels each having time integration effects and a part of
the continuity of the real world light signals has been
lost; a movement vector setting step for setting movement
vectors of an object within the image data corresponding to
10   the continuity of the real world light signals of which a
part of the continuity has been lost in the image data; a
model generating step for modeling the region between pixel
values of each of the pixels within the processing region
and pixel values of each of the pixels where there is no
15   movement blurring, with the understanding that the pixel
values of each of the pixels within the processing region
are values obtained by pixel values of each of the pixels
without movement blurring as to the object being integrated
while moving corresponding to a movement vector; a normal
20   equation generating step for generating normal equations
from a first equation wherein the pixel values of the pixels
within the processing region have been substituted into a
model generated in the model generating step, and a second
equation for constraining the relation between the pixels
25   where there is no movement blurring; an activity detecting

step for detecting the activity corresponding to each of the

pixels within the processing region; a weight changing step

for changing the weighting as to a part of the first and

second equations according to the detection results in the

5 activity detecting step; and an actual world estimating step

for estimating the pixel values of each of the pixels where

there is no movement blurring, by computing the normal

equations generated by the normal equation generating step

and of which the weighting has been changed in the weight

10 changing step.

Industrial Applicability

As described above, according to the present invention,

images and the like closer approximating real world signals

can be obtained.